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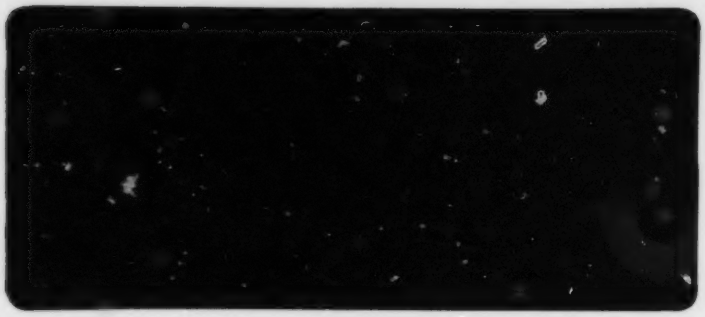

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GEOTECHNICAL TESTING OF OILSANDS

BOOK ONE OF TWO

TITLE: **GEOTECHNICAL TESTING OF OILSANDS**

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EXECUTIVE SUMMARY

Petro-Canada Inc. (PCI) is using cyclic steam stimulation at the PCEJ Hangingstone Pilot to extract bitumen from the McMurray formation. The propagation of pressurized steam into the oilsand reservoir is inhibited by the low permeability of the formation caused by the immobility of the highly viscous bitumen. Therefore, the oil sands are hydraulically fractured to provide the paths for the steam to travel from the injection well out into the reservoir. This report documents a combined laboratory and simulation study aimed at estimating the amount of dilation to be used in the reservoir model to predict fracture growth and production performance.

The purpose of laboratory testing was to acquire geomechanical and permeability data required by the fracture design model. The laboratory work was carried out on samples in the vicinity of the PCEJ Hangingstone Pilot's steam injection wells. Geomechanical parameters such as, deformation modulus, bulk compressibility, shear dilation, absolute permeability and effective permeability to water were measured in a triaxial cell along the stress path representative of injection (unloading) and production cycle (reloading) at the fracture face. Additional testing was also carried out to define the shear strength of the reservoir materials.

The results of the testing have demonstrated that the geomechanical properties vary significantly at a single site. A number of samples provided for testing experienced excessive expansion caused by overcoring and parameters derived from these specimens may not be representative of in-situ behaviour. The data obtained from the testing program indicates that permeability is significantly influenced by the pressure and orientation of shear surfaces. Fluid flow in the shear dilation zone around a propagating fracture is highly anisotropic.

After the labratory testing of the samples, x-radiography was used to x-ray the internal structures of the samples. The pictures identify the type of sand, the location and appearance of induced fractures.

The purpose of the simulation study was to use the geomechanical data measured in the laboratory, and the 2-D finite element model ENHANSE to determine the reservoir parameters to be used in the fracture design model. First, a new generalized hyperbolic model of the stress-strain behaviour was reconstructed from three measured laboratory experiments. An excellent match of stress-strain and volumetric strain (dilation) was achieved.

Second, a field injection case was simulated for a stationary, horizontal fracture configuration with the new model. In order to determine the amount of shear dilation, simulations with and without dilation were compared. The results show that the majority of the volumetric strain (about 3%) is caused by the unloading of the oil sand and only small amounts (about 0.3%) by a dilation mechanism. This is in contrast to the lab data which shows large dilation (several %). The difference was explained in terms of different stress paths between the lab and field cases.

Finally, two hypothetical laboratory experiments were simulated along the stress paths seen in the field case (Step 2) to check the consistency of the model. The volumetric behaviour of the hypothetical laboratory experiments were similar to the elements of the field model which confirms the consistency of the model.

SOMMAIRE-RECOMMANDATION

Petro-Canada Inc. (PCI) utilise la stimulation par injection cyclique de vapeur dans le cadre du projet pilote Hangingstone de la PCEJ pour extraire du bitume de la formation de McMurray. La propagation de la vapeur sous pression dans le gisement de sables bitumineux est entravée par la faible perméabilité de la formation, attribuable à la grande viscosité du bitume. Par conséquent, les sables bitumineux font l'objet d'une fracturation hydraulique pour créer des passages permettant à la vapeur de se rendre du puits d'injection jusqu'au réservoir. Le présent rapport porte sur une étude en laboratoire et une étude de simulation visant à estimer le degré de dilatation devant être appliqué au modèle de réservoir pour prévoir l'accroissement de la fracturation et la performance de la phase de production.

L'objet des essais de laboratoire était d'acquérir les données géomécaniques et de perméabilité nécessaires à l'établissement d'un modèle de fracture. Les travaux en laboratoire ont été effectué sur des échantillons prélevés dans les environs des puits d'injection de vapeur du projet pilote Hangingstone. Des paramètres géomécaniques tels que le module de déformation, la compressibilité, la dilatation par cisaillement, la perméabilité absolue et la perméabilité réelle à l'eau ont été mesurés dans une cellule triaxiale le long du chemin de contrainte représentatif de l'injection (décompression) et du cycle de production (recompression) sur le plan de la fracture. Des essais supplémentaires ont également été effectués pour déterminer la résistance au cisaillement des matières du réservoir.

Les résultats de ces essais ont démontré que les propriétés géomécaniques varient de façon importante à un même endroit. Certains échantillons fournis pour les essais ont subi une expansion excessive attribuable au surcarottage et il est possible que les paramètres établis selon ces échantillons ne soient pas représentatifs du comportement in situ. Les données obtenues dans le cadre du programme d'essai indiquent que la perméabilité dépend dans une large mesure de la pression et de l'orientation des surfaces de cisaillement. La circulation de fluide dans la zone de dilatation par cisaillement autour d'une fracture qui se propage est hautement anisotrope.

Après avoir soumis les échantillons aux essais de laboratoire, on les a radiographiés pour en connaître la structure interne. Les radiographies permettent de déterminer le type de sable de même que l'emplacement et l'apparence des fractures provoquées.

L'objet de l'étude de simulation était d'utiliser les paramètres géomécaniques mesurés en laboratoire et le modèle bidimensionnel à éléments finis ENHANSE pour déterminer les paramètres du réservoir à utiliser pour l'établissement du modèle de fracture. D'abord, un nouveau modèle hyperbolique généralisé du comportement de contrainte-déformation a été reconstruit à partir des données de trois expériences de laboratoire. On a obtenu une excellente corrélation entre le comportement de contrainte-déformation et la déformation volumétrique (dilatation).

Ensuite, à l'aide du nouveau modèle, un cas d'injection sur champ a été simulé pour une fracture stationnaire et horizontale. Afin de déterminer le degré de dilatation au cisaillement, on a comparé des simulations avec et sans cisaillement. Les résultats démontrent que la plus grande partie de la déformation volumétrique (environ 3 %) est causée par la décompression du sable bitumineux et seulement une faible portion de cette déformation (environ 0,3 %), par un mécanisme de dilatation. Ces résultats ne concordent pas avec les données de laboratoire qui indiquent une dilatation importante (plusieurs points de pourcentage). Cet écart s'explique par les différents chemins de contrainte des cas en laboratoire et des cas sur champ.

Finalement, deux expériences hypothétiques en laboratoire ont été simulées le long des chemins de contrainte observés dans le cas sur champ (deuxième étape) pour vérifier la pertinence du modèle. Les comportements volumétriques observés dans le cadre de ces expériences hypothétiques sont semblables aux éléments de la modélisation sur champ, ce qui confirme que le modèle est approprié.

GEOTECHNICAL TESTING OF OILSANDS

GOLDER ASSOCIATES LTD.

Golder Associates Ltd.
CONSULTING ENGINEERS

REPORT TO PETRO-CANADA RESOURCES INC. ON GEOTECHNICAL TESTING OF OIL SANDS CORE

PCEJ PILOT PROJECT

Distribution:

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1.0 INTRODUCTION

Cyclic steam stimulation is being employed at the PCEJ oil sands pilot project in the Athabasca Deposit to recover bitumen from the McMurray Formation. The oil sands are fractured to provide paths for the steam from the injection well out into the reservoir. The economical viability of the steam stimulation process is therefore dependent on the design and implementation of successful fracture strategies.

Petro-Canada Inc. (PCI) is carrying out numerical fracture design modelling using SIMTECH's TARSIM system for the PCEJ project. PCI has attained samples from the reservoir in the vicinity of the injection wells for testing to determine geomechanical properties which can be used to derive reliable and representative model input parameters. This report describes a laboratory testing project to acquire geomechanical and permeability data required by the fracture design model.

1.1 Background

The geomechanical properties of oil sands have been studied extensively over the years as geotechnical problems associated with oil sands development have arisen. A fundamental understanding of the mechanical characteristics of oil sands and the methods and procedures required to measure representative properties has evolved from these investigations. The geomechanical properties of oil sands formation strata have been found to be controlled by the temperature, pressure and stress path followed during the laboratory test. The vast majority of experimental work carried out to date has involved subjecting samples to stress and temperature changes not representative of those which would occur during hydraulic fracturing. As a result, these data cannot be used with confidence to derive input parameters for fracture design models. In addition, in situ deposits exist under the influence of many geological factors which vary from deposit to deposit and may vary through

the vertical and lateral extent of a particular deposit. As a consequence of the fundamental effects of geology on constitutive behaviour, detailed core sampling and laboratory testing is often required to attain realistic geomechanical input parameters for each site.

1.2 Objectives

The major objective of the laboratory testing program described in this report was to measure the necessary geomechanical parameters required in the numerical modelling of hydraulic fracture propagation and subsequent fluid withdrawal during production cycles at the PCEJ pilot project. Laboratory tests were to match stresses appropriate to the in situ stimulation and recovery processes as closely as possible. Laboratory procedures were to utilize sample preparation and testing techniques that preserve integrity of the oil sands matrix in order to produce geomechanics properties representative of in situ values.

1.4 Authorization

The project was initiated by PCI's Request for Proposal dated October 18, 1989. Golder Associates submitted a proposal to carry out the testing on October 19, 1990. Authorization to proceed with the project was provided through Petro-Canada Services Agreement dated January 2, 1990.

2.0 TEST EQUIPMENT AND PROCEDURES

This section describes the equipment and test procedures used for the project. The tests were carried out in Golder Associates' laboratory in Calgary.

2.1 Test Equipment

The testing equipment employed for this project included a triaxial cell which can operated at confining pressures up to 14 MPa, a positive displacement pump to apply pore fluid pressure to the test specimen, a programmable GDS pressure controller/pressure intensifier assembly for applying radial stress to the test specimen, and a strain controlled axial loading system to apply vertical loads to the test specimen. Pore fluid pressures, axial stress, radial stress, axial strain and volume change during a triaxial test are measured electronically using an IBM based computer data acquisition system. Interchangeable load platens allow the testing of specimens ranging from 38 mm to 76 mm in diameter and 76 mm to 152 mm in height. The dimension of specimens used in this laboratory program were approximately 54 mm diameter by 108 mm in height.

2.2 Sample Preparation and Test Procedures

2.2.1 Sample Preparation

In order to obtain geomechanical properties in the laboratory which are representative to those which exist in the field it is essential to limit the amount of sample disturbance during coring, transportation, storage and sample preparation. Oil sands and shale samples are handled differently. During core sampling of oil sands from boreholes, confining stresses and pore fluid pressures are reduced rapidly and gas evolution from the bitumen and water may occur. This formation of gas bubbles combined with the lack of cementation (i.e. cohesive strength)

between sand grains results in expansion of the oil sands fabric. If the amount of sample disturbance caused by core expansion is significant, the interlocking contacts at grain boundaries are lost and geomechanical behaviour is adversely affected. At the present time the most successful methods to minimize sample damage in oil sands are techniques which employ freezing, reduced clearance between core sample and liner and which provide axial and radial restraint to core expansion. Cores of shale taken from boreholes should be capped, sealed and stored at room temperature. Shale samples subjected to freezing may experience significant damage. The core liner must not be permitted to flex during handling as this will result in cracking of the shale. After transport from the field it is essential that shale samples be stored under controlled humidity conditions to prevent dehydration.

The core samples used in this testing program were received from Core Laboratories, sealed and frozen in sections of plastic core liners. These core samples were stored in a freezer at Golder Associates at -20 to -25°C.

When an oil sands sample was required for testing a piece of frozen core was placed in an insulated receptacle and covered with dry ice. The core was left in the dry ice (at approximately -78°C) for several hours. The piece of highly frozen core was machined to the desired test specimen diameter in a lathe situated in a cold room. To inhibit swelling of the specimen from heat developed during machining, the sample was trimmed in stages. The sample was placed in dry ice for several minutes between each stage. After the sample was machined to the correct diameter it was cut to the required length using a saw which was also located in the cold room. The final stage of sample preparation involved machining the ends of the sample flush and smooth. The test sample was mounted in the triaxial cell in the cold room prior to transfer to the testing laboratory. Final assembling of the triaxial cell, confining the sample under vertical and horizontal stresses, and raising the sample fluid pressure was accomplished before the sample thawed. The stresses

and fluid pressure selected were sufficiently high that further sample disturbance would not occur.

2.2.2 Test Program and Procedures

The laboratory work consisted of three basic types of tests:

TASK 1 TESTS - MEASUREMENT OF GEOMECHANICAL PROPERTIES

Geomechanics parameters were measured in a triaxial cell along the stress path representative of injection (unloading) and production cycle (reloading) at the fracture face. Deformation modulus and bulk compressibility were determined as a function of minor principal effective stress during isotropic unloading from the in situ stress state and subsequent reloading past the initial stress. Volumetric strain was also measured during unloading, failure and reloading. This determines the amount of dilation which takes place during failure.

TASK 2 TESTS - MEASUREMENT OF FLUID FLOW PROPERTIES

This task involved measuring the changes in absolute permeability as a function of effective stress and strain. Absolute permeability was measured along the same unloading-reloading cycles described in Task 1 Tests. Prior to testing, the specimen was flooded with toluene to extract bitumen from the specimen by solution. A cyclic procedure of alternate soaking and flushing with toluene was repeated until all bitumen was removed from the specimen. Permeability tests were performed on the oil free sand specimens. Effective permeability to water was measured. The relationship between absolute permeability and minor principal effective stress was derived.

TASK 3 TESTS - MEASUREMENT OF OIL SAND YIELD CRITERIA

Friction angle of the oil sands as a function of minor principal effective stress and cohesion was derived from shear strength data obtained from consolidated passive compression tests carried out over a range of effective confining stresses.

Detailed test procedures for each group of tests are given in Appendix I. It is noted that the procedures described above were modified at the request of PCI for some tests. These changes included:

Task 1 Tests

- Some tests were modified to permit greater yielding at failure envelope.
- One test was subjected to three cycles of proportional loading and unloading.

Task 2 Tests

- Some tests were modified to allow greater yielding at failure envelope
- One test was carried out without removing bitumen. This test was also subjected to three cycles of proportional loading and unloading.

Task 3 Tests

- Two tests were carried out at a temperature of 100°C.
- Two additional stress paths to define the extension failure envelope were carried out.
- Some tests were subjected to three cycles of axial loading and unloading.

2.3 Materials Tested

Five major facies were examined in the testing program:

1. Laminar. Shale laminated oil sands underlying the oil sands of the lower McMurray Formation.

2. Lower Sand. Oil sands comprising the lower portion of the McMurray Formation.

3. Shale. Shale overlying and underlying the Upper McMurray depositional unit.

4. Upper Sand. Oil sands forming the upper portion of the McMurray Formation.

5. Clasts. Oil sands containing discontinuous shale seams and clasts found above the upper oil sands unit of the McMurray Formation.

Core samples were obtained from 6 boreholes at the PCEJ site - B_1, B_2, C_1, C_3, D_1 and D_2. The core samples were received at Golder Associates' Calgary Laboratory inside plastic core liners which were sealed and frozen. One shale core sample attained from borehole C_1 was received unfrozen and was stored in a humid room to prevent desiccation.

3.0 TEST RESULTS

3.1 General

Test specimens in this report are identified by their well number, core preserve number and type of test as follows:

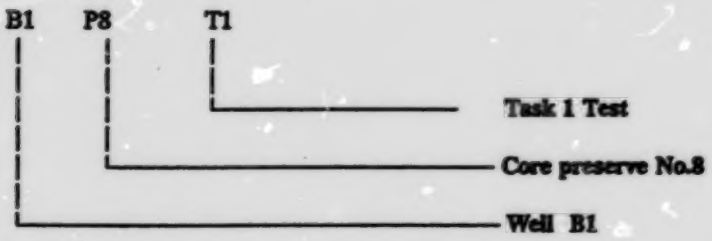

Table 1 gives the geological unit, depth interval and type of test for each sample examined in the laboratory program. The initial bulk density, mass percentage of water, bitumen and solids, and initial porosity of each test specimen is summarized in Table 2. Also shown in Table 2 are the pore pressure parameter B measured under and effective confining stress of 0.2 MPa and the index of disturbance for each test specimen.

The pore pressure parameter B is the measure of the undrained pore fluid pressure response of the specimen to a change in isotropic stress. This value is used to determine the pore fluid pressure required to fully saturate the test specimens. After the test specimen has thawed completely, the confining and pore pressures are raised in equal increments and the pore pressure parameter B is measured following each increment. By maintaining a constant effective confining stress on the specimen during each increase in pore fluid pressure the soil structure does not compress and the pore fluid saturation pressure is determined when the B parameter becomes constant. For most oil sands specimens the pore fluid saturation pressure ranges from 2.0 to 2.5 MPa (this pressure depends on the time

allowed for dissolving the gasses). The B values at saturation pressure are given in Table 3.

The index of disturbance is used to compare the in situ porosity n of a given oil sand with laboratory derived porosity n_e and is defined as:

$$I_D = \frac{n_e - n}{n}$$

In situ porosity can be determined from geophysical logging performed on the core holes. Since the presence of free gas in an oil sands reservoir is rare, however, in situ porosity can be calculated from laboratory measurements by:

$$n = \frac{\frac{M_w}{G_w} + \frac{M_b}{G_b}}{\frac{M_w}{G_w} + \frac{M_b}{G_b} + \frac{M_s}{G_s}}$$

Where:

M_w = mass of water
M_b = mass of bitumen
Ms = mass of mineral grains
G_w = specific gravity of water
Gb = specific gravity of bitumen
G_s = specific gravity of mineral grains

To obtain representative values of geotechnical and petrophysical properties, an index of disturbance in the order of 15% or less is required.

Table 3 gives the pore pressure parameter B, bulk compressibility and porosity of the test specimens after stressing to in situ conditions.

3.2 Task 1 Tests

The results of Task 1 tests are summarized in Tables 4 through 6 and presented graphically in Appendix II. Two specimens from the lower unit (B1P8T1 and B2P7T1) and one specimen from the upper sand (B1P4T1) were tested following the procedure described in Appendix I. The stress path followed during these tests is shown in Figure 1 and 2. Briefly, the ratio of horizontal to vertical effective stress (K_o value) estimated by PCI to exist in the reservoir was applied to each test specimen after the thaw period ended. The magnitude of these stresses was then increased until the assumed stress levels in the reservoir strata were reached. To simulate the stress path associated with fluid injection during the fracture process, the axial and radial effective stresses were decreased in equal increments (isotropically) until shear failure occurred. This stress path is referred to as a "proportional unloading" path and was performed by maintaining constant horizontal and radial stresses on the specimen and increasing the pore fluid pressure (Figure 1). Failure was determined during the test when the shear strain in the specimen began to increase rapidly under constant stress conditions. At the onset of failure the effective stresses on the sample were increased isotropically by reducing the pore fluid pressure. The shear deformation was therefore arrested. The stresses were increased to 1 MPa above in situ conditions. This portion of the stress path was intended to simulate fluid withdrawal from the reservoir after fracturing the reservoir.

Data from the three Task 1 tests indicate that subjecting test specimens to the proportional unloading/loading stress path while restricting dilation at the shear failure envelope results in small changes in specimen porosity, Young's modulus and bulk modulus. It is noted that modulus values generally increase during initial unloading which may be attributed to residual sample disturbance at the start of the test due to coring. The trends observed in these tests were expected since the

deviatoric stress did not change during the test (Figure 2) and therefore significant non-recoverable or "plastic" strain should not occur.

The test procedure for Task 1 was modified for the remaining tests to permit greater yielding at the failure envelope. In all cases the amount of dilation during shear straining was significant resulting in porosity changes of up to 4% (Table 6). The lower modulus values on reloading are due to the increase in porosity.

Specimen C3P3T1 was subjected to three cycles of unloading, shear and reloading. The amount of dilation after each stage of proportional unloading decreased with the majority of the decrease occurring after the first cycle. This reflects renewed movement along shear surfaces formed during initial shearing.

3.3 Task 2 Tests

The results of Task 2 testing are tabulated in Tables 7 and 8. Individual test plots are contained in Appendix III.

Specimens B2P7T2 and B2P3T2 were carried out following the test procedures described in Appendix I. It is noted porosity measurements from specimen B2P7T2 were not available. The change in absolute permeability during these tests was small because the strains developed at the failure envelope were small.

The procedure for the remaining tests was altered to permit free dilation at the failure envelope. The porosity increase due to shear dilation ranged from 1.2 to 2.8%. Four of the six tests showed a decrease in permeability even though the porosity of the specimens increased due to shear dilation. This may be due to disruption of flow paths across the planes of intense shear which form as the specimen yields at the failure envelope. It is noted, however, that in these tests, permeability was always measured parallel to the axis of the core. In contrast, the

orientation of the shear surfaces were observed to cut across the core axis. Given the heterogeneous nature of the specimens after shear it is likely the permeability of the specimen would be highly anisotropic. That is, even though the permeability of the specimen may decrease when flow is across the shear plane, permeability parallel to the shear plane may be significantly higher.

Specimen C3P3T2 was subjected to three cycles of proportional unloading, shear and reloading. The bitumen was not flushed from this specimen prior to testing. The amount of shear dilation after the second and third unloading was significantly lower than during initial shear. The change in permeability also does not vary significantly after the initial shearing. The major disruption in the fabric of the specimen appears to be associated with the formation of the shear surface. Subsequent movement along these plane(s) appears to have little effect on permeability measurements. This result is consistent with Task 1 testing.

The permeability decreased after shear dilation in 4 of the 6 specimens tested. Permeability is therefore influenced by the presence and orientation of shear surfaces. Permeability after shear dilation is likely to be highly anisotropic.

3.4 Task 3 Tests

Table 9 summarizes the results of the Task 3 tests. Individual test plots are contained in Appendix IV.

The stress paths employed in Task 3 testing are given in Figure 3. The initial test procedure (see Appendix I) involved increasing the major principal effective stress, σ'_1, applied to the specimen while holding the intermediate and minor principal

effective stresses, σ'_2 and σ'_3, constant and equal. This is referred to as "passive compression". Prior to these tests the sample was consolidated to in situ stress conditions following an isotropic compression stress path ($K_o = 1$) . Performing tests at a minimum of three effective confining stresses (σ'_3) (e.g. Test 1, Tests 2 and Test 3 paths in Figure 3) allows definition of the shear failure envelope in compression.

The results of Task 3 tests carried out on the lower sand are plotted in terms of Mohr-Coloumb diagram in Figure 4. A linear failure line can be drawn tangent to the stress circles resulting in an angle of internal friction of 39.5° and an apparent cohesion, c', of 60 kPa.

Two additional stress paths were considered during triaxial strength testing of the upper sand unit:

1. The axial stress, σ'_1, was held constant and the radial stress, σ'_3, was increased.

2. The radial stress was held constant and the axial stress was decreased.

Both stress paths are illustrated in Figure 3. These stress paths (labelled A and B in Figure 3) may be classed as "extension stress paths" as they terminate at and define the location at the shear failure envelope in extension. The shear strength test results are plotted in terms of a Mohr-Coulomb diagram in Figure 5. The failure line in compression is defined by the strength parameters ϕ' = 49° and c' = 0. The extension failure line is described by the Mohr-Coulomb parameters ϕ' = 41° and c'= 70 kPa.

Triaxial shear strength tests carried out at 100°C are also shown in the figure. These specimens were saturated and subjected to cyclic loading above in situ stresses before heating. It is noted that the deviatoric stress at failure ($\sigma'_1 - \sigma'_3$) for the specimens tested at 100°C is larger than the specimens tested at 20°C even though the effective confining stresses and procedures used in the tests were identical. Specimens D2P8T3T and D2P8T3B were taken from the same core sample so the results may be expected to be similar. The increase in strength may be attributed to heat consolidation of the shale interbedding and thermally induced rearrangement of the sand grain structure. Table 9 indicates that the deformation modulus is also higher for the specimens heated to 100°C under drained conditions before testing. Improvements in strength and deformation properties associated with volume reduction caused by heat consolidation is well documented in the literature (e.g. Kosar, 1989; Green, 1984; Williams, 1982; Campanella and Mitchell, 1968, etc.).

Figure 6 is a plot of the shear strength test results for the shale strata. A linear failure line drawn through these test values gives an apparent cohesion value of c' = 300 kPa and gives an angle of internal friction of ϕ' = 48°.

4.0 RECOMMENDATIONS

This report has documented the results of laboratory tests carried out on the reservoir materials present at the PCEJ pilot in the Athabasca Deposit. The purpose of the testing program was to attain representative geomechanical properties which could be used to derive input parameters for the numerical model to be used for fracture design. The following recommendation are based on the results of the laboratory study:

1. About 20% of the oil sands specimens tested in this study are classed as high quality undisturbed specimens with index of disturbance values less than 15%. Some specimens, however, had disturbance values in excess of 45%. The parameters derived from the more disturbed specimens may not be representative of in situ behaviour and therefore should be used with caution in numerical simulations. More attention should be paid to core sampling procedures in the future. Methods which employ freezing, reduced clearance between core sample and liner, and provide mechanical axial and radial restraint to core expansion are most successful at the present time in minimizing sample damage. The cost of employing the methods is relatively small compared to overall drilling costs.

2. The permeability change due to shear dilation around a propagating fracture is a significant parameter in fracture design. The data obtained from the testing program indicates that permeability is significantly influenced by the presence and orientation of shear surfaces. Fluid flow in the shear dilation zone may therefore be highly anisotropic. Future testing should include permeability measurements in several directions to the shear surface to provide more representative values to the numerical model.

3. The results of this testing have demonstrated that the mechanical properties of geological facies can vary significantly, even at a single site. This fact stresses the importance of carrying out site specific geomechanical properties testing to provide rational input parameters to fracture studies.

GOLDER ASSOCIATES LTD.

PROFESSIONAL ENGINEER K. M. KOSAR Oct 5, 1990 KMK

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The Association of Professional Engineers, Geologists and Geophysicists of Alberta

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TABLE 1 Geomechanical Testing of Oil Sands Core - Summary

Sample Number	Geological Unit	Depth Interval (m)	Bitumen Extraction Required Yes/No	Bitumen Extraction Complete Yes/No	Type of Test
B1P8T1	Lower Sand	316.75 - 317.10	No		Task 1
B1P8T3	Lower Sand	316.75 - 317.10	No		Task 3
B2P7T1	Lower Sand	329.20 - 329.55	No		Task 1
B2P7T2	Lower Sand	329.20 - 329.55	Yes	Yes	Task 2
B2P7T3	Lower Sand	329.20 - 329.55	No		Task 3
B1P4T1	Upper Sand	295.68 - 296.03	No		Task 1
B1P4T3	Upper Sand	295.68 - 296.03	No		Task 3
B2P3T1	Upper Sand	308.47 - 308.82	Yes	Yes	Task 1
B2P3T2	Upper Sand	308.47 - 308.82	No		Task 2
B2P3T3	Upper Sand	308.47 - 308.82	No		Task 3
B2P1T1	Upper Sand	296.86 - 297.22	Yes	Yes	Task 1
B2P1T2	Upper Sand	296.86 - 297.22	No		Task 2
B2P1T3	Upper Sand	296.86 - 297.22	No		Task 3
C1P4T1	Lower Sand	313.45 - 313.80	Yes	Yes	Task 1
C1P4T2	Lower Sand	313.45 - 313.80	No		Task 2
C1P4T3	Lower Sand	313.45 - 313.80	No		Task 3
C1P2T1	Upper Sand	290.81 - 291.16	Yes	Yes	Task 1
C1P2T2	Upper Sand	290.81 - 291.16	No		Task 2
C1P2T3	Upper Sand	290.81 - 291.16	No		Task 3
C3P2T1	Upper Sand	328.20 - 328.61	Yes	Yes	Task 1
C3P2T2	Upper Sand	328.20 - 328.61	No		Task 2
C3P2T3	Upper Sand	328.20 - 328.61	No		Task 3
C3P3T1	Upper Sand	328.99 - 329.37	Yes	Yes	Task 1
C3P3T2	Upper Sand	328.99 - 329.37	No		Task 2
D1P9T2B	Lower Sand	313.89 - 314.25	No		Task 3 (3 cycles)
D1P9T2	Lower Sand	313.89 - 314.25	Yes		Task 1 (3 cycles)
D2P6T1	Lower Sand	314.90 - 315.06	Not available	Not available	Task 2 (not flushed)
D2P6T3	Lower Sand	314.90 - 315.06	Yes		Task 2
D1P7T3C	Upper Sand	300.46 - 300.82	Not available		Task 2
D1P7T3B	Upper Sand	300.46 - 300.82	No		Task 1
D1P7T3	Upper Sand	300.46 - 300.82	No		Task 3
D2P4T3C	Upper Sand	305.54 - 305.87	No		Task 3 KO>1
D2P4T3B	Upper Sand	305.54 - 305.87	No		Task 3 KO>1
D2P4T3	Upper Sand	305.54 - 305.87	No		Task 3
D1P3T1	Clasts	290.81 - 291.05	No		Task 3 KO>1
D1P3T2	Clasts	290.81 - 291.05	No		Task 3 KO>1
D1P10T1	Laminar	316.23 - 316.51	No		Task 3
D1P10T3	Laminar	316.23 - 316.51	Yes		Task 3, 3 Cycles
D2P8T3T	Laminar	327.82 - 328.21	Yes	No	Task 3, 3 Cycles
D2P8T3B	Laminar	327.82 - 328.21	No	No	Task 3 T=100C
D2P8T3	Laminar	327.82 - 328.21	No		Task 3
B1P2T3	Shale	283.00 - 283.38	No		Task 3 T=100c
B1P7T3	Shale	308.41 - 308.70	No		Task 3
C1P1T3	Shale	273.51 - 273.86	No		Task 3
D2P1T3	Shale	286.60 - 286.99	No		Task 3
			No		Task 3
			No		Task 3

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TABLE 2 Initial Conditions of Oil Sands and Related Strata Core Samples

Sample Number	Geological Unit	Bulk Density (Mg/m3)	% Water (mass)	% Bitumen (mass)	% Solids (mass)	Porosity (%)	B Value (0.2 MPa)	Index of Disturbance (%)
B1P8T1	Lower Sand	1.74	4.8	15.1	80.1	47.1	0.89	20.0
B1P8T3	Lower Sand	1.76	4.8	15.1	80.1	46.8	0.95	18.4
B2P7T1	Lower Sand	1.79	2.8	16.4	80.8	45.4	0.90	18.2
B2P7T2	Lower Sand	1.80	2.8	16.4	80.8	45.1	0.85	17.4
B2P7T3	Lower Sand	1.90	2.8	16.4	80.8	42.5	0.98	10.2
B1P4T1	Upper Sand	1.90	1.8	15.5	82.7	40.8	0.92	14.8
B1P4T3	Upper Sand	1.85	1.8	15.5	82.7	42.3	0.87	19.1
B2P3T1	Upper Sand	1.71	1.0	17.7	81.3	47.5	0.97	26.3
B2P3T2	Upper Sand	1.67	1.0	17.7	81.3	49.2	0.95	30.0
B2P3T3	Upper Sand	1.64	1.0	17.7	81.3	50.1	0.96	32.4
B2P1T1	Upper Sand	1.90	3.1	15.4	81.5	41.5	0.97	11.2
B2P1T2	Upper Sand	2.00	3.1	15.4	81.5	39.0	0.96	3.9
B2P1T3	Upper Sand	1.78	3.1	15.4	81.5	45.7	0.96	21.8
C1P4T1	Lower Sand	1.70	4.0	16.1	79.9	48.7	0.89	22.5
C1P4T2	Lower Sand	1.73	4.0	16.1	79.9	48.4	0.93	21.1
C1P4T3	Lower Sand	1.72	4.0	16.1	79.9	48.2	0.96	21.1
C1P2T1	Upper Sand	1.61	2.7	16.2	81.1	51.5	0.94	29.3
C1P2T2	Upper Sand	1.65	2.7	16.2	81.1	49.9	0.93	31.0
C1P2T3	Upper Sand	1.68	2.7	16.2	81.1	49.0	0.97	28.5
C3P2T1	Upper Sand	1.88	3.5	9.1	87.4	38.0	0.92	27.5
C3P2T2	Upper Sand	1.82	3.5	9.1	87.4	40.4	0.93	46.5
C3P2T3	Upper Sand	1.83	3.5	9.1	87.4	40.1	1.00	45.3
C3P3T1	Upper Sand	1.78	2.0	12.7	85.3	42.3	0.99	38.1
C3P3T2	Upper Sand	1.77	2.0	12.7	85.3	43.5	0.98	39.0
D1P9T2B	Lower Sand	1.70	1.5	17.5	81.0	46.3	0.95	26.3
D1P9T2	Lower Sand		Not Tested					
D2P6T1	Lower Sand	1.52	4.9	16.0	79.1	54.7	0.95	33.4
D2P6T3	Lower Sand		Not Tested					
D1P7T3C	Upper Sand	1.97	1.8	15.0	83.2	38.7	0.95	11.1
D1P7T3B	Upper Sand	1.71	1.8	15.0	83.2	46.7	0.87	34.1
D1P7T3	Upper Sand	1.69	1.8	15.0	83.2	47.5	0.95	36.4
D2P4T3C	Upper Sand	1.78	1.2	15.5	83.3	44.5	0.97	28.6
D2P4T3B	Upper Sand	1.75	1.2	15.5	83.3	45.4	0.94	31.1
D2P4T3	Upper Sand	1.73	1.2	15.5	83.3	46.0	0.95	32.8
D1P3T1	Clasts	1.81	2.8	15.1	82.1	44.5	0.91	21.6
D1P3T2	Clasts	1.98	2.8	15.1	82.1	39.0	0.88	6.7
D1P10T1	Laminar	1.81	3.2	14.9	81.9	44.4	0.97	20.5
D1P10T3	Laminar	1.80	3.2	14.9	81.9	44.9	0.97	21.8
D2P8T3T	Laminar	1.80	3.3	16.6	80.1	46.2	0.95	16.4
D2P8T3B	Laminar	1.76	3.3	16.6	80.1	47.2	0.97	18.9
D2P8T3	Laminar	1.76	3.3	16.6	80.1	47.2	0.95	19.1
B1P2T3	Shale		Not Tested					
B1P7T3	Shale	2.17	11.6	0.0	88.4	29.3	0.93	----------
C1P1T3	Shale	2.20	11.3	0.0	8.7	28.3	0.95	----------
D2P1T3	Shale	2.14	11.7	0.0	8.3	30.7	0.99	----------

TABLE 3 Oil Sands and Related Strata Core Samples after Stressing to In Situ Conditions

Sample Number	Geological Unit	Pore Pressure Parameter B	Bulk Compressibilty (MPa)	Porosity (%)	Comments
B1P8T1	Lower Sand	----	364.38	46.10	
B1P8T3	Lower Sand	0.96 (0.5 MPa)	550.50	45.06	
B2P7T1	Lower Sand	0.48	301.33	43.60	
B2P7T2	Lower Sand	----	----	----	
B2P7T3	Lower Sand	0.88	659.57	37.79	
B1P4T1	Upper Sand	0.50	344.32	38.88	
B1P4T3	Upper Sand	0.79 (0.5 MPa)	585.74	40.81	
B2P3T1	Upper Sand	----	170.40	45.10	
B2P3T2	Upper Sand	0.74	539.06	41.03	
B2P3T3	Upper Sand	0.86	582.83	47.22	
B2P1T1	Upper Sand	0.69	317.24	40.87	
B2P1T2	Upper Sand	0.63	592.88	33.12	
B2P1T3	Upper Sand	0.84	612.97	43.29	
C1P4T1	Lower Sand	0.88(before stress cycle)	344.93	46.31	
C1P4T2	Lower Sand	0.64	600.50	37.54	
C1P4T3	Lower Sand	0.81	618.84	46.36	
C1P2T1	Upper Sand	0.94(before stress cycle)	156.25	49.02	
C1P2T2	Upper Sand	0.62	496.50	42.16	
C1P2T3	Upper Sand	0.87	637.79	46.75	
C3P2T1	Upper Sand	0.49	328.51	36.47	
C3P2T2	Upper Sand	0.93(before stress cycle)	617.74	36.88	
C3P2T3	Upper Sand	0.86	415.17	37.98	3 cycles
C3P3T1	Upper Sand	0.69	167.93	41.43	
C3P3T2	Upper Sand	0.66	615.51	31.30	
D1P9T2B	Lower Sand	0.66	438.05	42.20	
D1P9T2	Lower Sand	Not Tested			
D2P6T1	Lower Sand	0.52	199.67	52.36	
D2P6T3	Lower Sand	Not Tested			
D1P7T3C	Upper Sand	0.91	553.86	36.93	Ko>1, 1 MPa
D1P7T3B	Upper Sand	0.84	284.25	43.93	Ko>1, 0.2 MPa
D1P7T3	Upper Sand	0.76	507.66	45.97	
D2P4T3C	Upper Sand	0.97	494.98	43.43	Ko>1, 0.5 MPa
D2P4T3B	Upper Sand	0.78	581.51	36.16	Ko>1, 0.5 MPa
D2P4T3	Upper Sand	0.76	542.25	44.39	
D1P3T1	Clasts	0.90	320.48	40.31	3 Cycles
D1P3T2	Clasts	0.51	543.73	41.66	3 Cycles
D1P10T1	Laminar	0.83	1042.80	42.53	
D1P10T3	Laminar	0.84	728.41	36.9	
D2P8T3T	Laminar	0.83	578.13	43.91	
D2P8T3B	Laminar	0.80	554.17	44.99	0.5 MPa
D2P8T3	Laminar	0.82	642.99	45.13	0.2 MPa
B1P2T3	Shale	Not Tested			
B1P7T3	Shale	0.65	756.69	26.24	
C1P1T3	Shale	0.58	312.06	24.55	
D2P1T3	Shale	0.81	778.39	28.43	

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TABLE 4 Task 1 Tests - Summary of Bulk Modulus Measurements

Bulk Modulus Values (MPa) along Proprotional Unloading- Reloading Stress Path

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3187	2687	2187	1687	1187	687	1187	1687	2187	2687	3187	3687	4187	Sample Permitted to Yield at Failure Envelope Yes/No
B1P8T1	Lower Sand	364.4	290.2	277.6	257.9	169.6	105.2	266.8	249.6	274.5	428.5	418.0	406.8	409.0	No
B2P7T1	Lower Sand	301.3	325.9	308.8	294.8	205.5	119.7	177.3	244.3	249.6	273.1	276.5	301.1	299.3	No
C1P4T1	Lower Sand	344.9	407.4	336.7	269.7	205.8	127.4	-----		Sample Failure			-----	-----	Yes
D1P9T1	Lower Sand														
D2P6T1	Lower Sand	199.7	368.8	336.3	285.1	198.6	174.1	111.8	147.1	187.1	215.5	232.3	246.2	249.4	Yes

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3104	2604	2104	1604	1104	604	1104	1604	2104	2604	3104	3604	4104	Sample Permitted to Yield at Failure Envelope Yes/No
B1P4T1	Upper Sand	344.3	363.2	323.4	270.9	203.0	109.4	176.2	238.3	268.9	303.4	344.5	337.8	395.1	No
B2P3T1	Upper Sand	170.4	315.8	279.2	256.6	174.2	39.8	78.5	108.9	137.3	145.0	157.6	167.9	160.8	Yes
B2P1T1	Upper Sand	317.2	116.2	328.1	611.5	190.6	102.7	----		Sample Failure			-----	-----	Yes
C1P2T1	Upper Sand	156.3	334.7	295.5	255.6	167.2	131.6	107.3	125.7	157.2	174.06	182.3	201.9	211.9	Yes
C3P2T1	Upper Sand	328.51	359.64	324.78	228.94	194.65	140.01	129.97	179.85	203.90	260.62	278.62	313.58	304.51	Yes
C3P3T1	Upper Sand	167.93	361.85	321.73	82.2	224.52	124.26	96.35	137.59	171.82	183.21	250.63			Yes
C3P3T1	cycle 2		367.61	328.08	278.73	210.12	128.83	134.63	198.31	228.54	257.71	285.9			Yes
C3P3T1	cycle 3		359.82	316.78	269.08	200.86	missed	122.94	192.34	240.57	269.05	298.07	326.14	311.15	Yes
D1P7T1	Upper Sand														
D2P4T1	Upper Sand														

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa)	Sample Permitted to Yield at Failure Envelope Yes/No
D1P3T1	Clasts		

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa)	Sample Permitted to Yield at Failure Envelope Yes/No
D1P10T1	Laminar		
D2P8T1	Laminar		

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TABLE 5 Task 1 Tests - Summary of Deformation (Young's) Modulus Measurements

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Young's Modulus Values (MPa) along Proprotional Unloading- Reloading Stress Path

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3187	2687	2187	1687	1187	687	1187	1687	2187	2687	3187	3687	4187	Sample Permitted to Yield at Failure Envelope Yes/No
B1P8T1	Lower Sand	258.1	543.3	602.5	569.1	506.3	385.9	482.0	585.5	639.5	668.5	734.8	770.3	799.1	No
B2P7T1	Lower Sand	302.0	639.6	543.9	566.6	629.6	427.6	572.5	635.9	827.5	1020.6	1054.4	1155.7	1291.8	No
C1P4T1	Lower Sand	257.3	500.3	513.9	550.1	341.0	209.3	-----		Sample Failure			-----	-----	Yes
D1P9T1	Lower Sand														
D2P6T1	Lower Sand	183.3	275.4	334.1	206.9	185.2	166.5	346.7	460.0	557.2	615.6	668.9	692.1	715.9	Yes

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3104	2604	2104	1604	1104	604	1104	1604	2104	2604	3104	3604	4104	Sample Permitted to Yield at Failure Envelope Yes/No
B1P4T1	Upper Sand	567.9	841.0	1141.7	1042.0	960.9	766.3	923.2	1194.9	1396.9	1539.3	1610.1	1903.6	2006.7	No
B2P3T1	Upper Sand	418.0	469.2	750.4	1004.7	748.7	70.8	123.6	455.0	696.8	646.9	1063.1	1195.8		Yes
B2P1T1	Upper Sand	773.4	970.1	948.7	889.1	818.7	640.0	-----		Sample Failure			------	------	Yes
C1P2T1	Upper Sand	302.2	468.1	479.3	302.4	164.5	110.7	268.4	430.8	650.0	588.0	703.1	738.7	799.4	Yes
C3P2T1	Upper Sand	581.01	754.89	913.31	703.32	625.63	587.05	421.53	675.570	820.57	916.09	969.08	1084.82	1140.84	Yes
C3P3T1	Upper Sand	588.2	693.9	698.5	651.6	577.4	379.1	577.5	656.3	718.8	747.0	813.6			Yes
C3P3T1	cycle 2		777.5	740.1	683.3	616.4	465.9	519.5	666.9	739.5	749.3	809.1			Yes
C3P3T1	cycle 3		785.8	751.1	677.9	524.0	missed	467.8	539.9	740.9	772.8	791.7	843.5	881.3	Yes
D1P7T1	Upper Sand														
D2P4T1	Upper Sand														

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa)	Sample Permitted to Yield at Failure Envelope Yes/No
D1P3T1	Clasts		

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa)	Sample Permitted to Yield at Failure Envelope Yes/No
D1P10T1	Laminar		
D2P8T1	Laminar		

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TABLE 6 Task 1 Tests - Summary of Porosity Measurements

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Porosity Values (%) along Proprotional Unloading- Reloading Stress Path

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3187	2687	2187	1687	1187	687	1187	1687	2187	2687	3187	3687	4187	Porosity Change at Failure Envelope (%)
B1P8T1	Lower Sand	46.2	46.2	46.5	46.6	46.8	47.4	47.3	47.1	47.2	47.2	47.1	47.0	46.9	0.28
B2P7T1	Lower Sand	43.5	43.5	43.6	43.7	43.8	44.0	43.8	43.6	43.5	43.3	43.1	43.0	42.9	0.01
C1P4T1	Lower Sand	46.2	46.3	46.4	46.5	46.6	46.8	--------		Sample Failure			--------		3.11
D1P9T1	Lower Sand														
D2P6T1	Lower Sand	52.4	52.4	52.4	52.5	52.6	52.7	53.4	53.1	52.9	52.7	52.5	52.4	52.2	1.00

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3104	2604	2104	1604	1104	604	1104	1604	2104	2604	3104	3604	4104	Porosity Change at Failure Envelope (%)
B1P4T1	Upper Sand	38.7	38.8	38.9	39.0	39.1	39.4	39.2	39.0	38.8	38.7	38.5	38.3	38.2	0.01
B2P3T1	Upper Sand	44.6	44.1	44.2	44.3	44.4	48.7	48.2	47.8	47.4	47.0	46.6	46.2	46.0	4.23
B2P1T1	Upper Sand	40.7	41.2	41.2	41.3	41.4	41.7	--------		Sample Failure			--------		3.30
C1P2T1	Upper Sand	49.0	49.0	49.0	49.1	49.3	49.5	50.7	50.4	50.1	49.9	49.6	49.4	49.1	1.54
C3P2T1	Upper Sand	36.4	36.5	36.5	36.7	36.9	37.1	38.8	38.5	38.3	38.1	37.9	37.7	37.6	1.95
C3P3T1	Upper Sand	41.4	41.5	41.6	42.1	42.3	42.6	44.6	44.3	44.1	43.8	43.7	--------		2.89
C3P3T1	cycle 2	--------	43.7	43.8	43.9	44.0	44.2	44.4	44.2	44.0	43.8	43.7	--------		0.49
C3P3T1	cycle 3	--------	43.8	43.8	43.9	44.1	--------	44.3	44.1	43.9	43.8	43.6	43.5	43.4	0.36
D1P7T1	Upper Sand														
D2P4T1	Upper Sand														

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa)	Porosity Change at Failure Envelope (%)
D1P3T1	Clasts		

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa)	Porosity Change at Failure Envelope (%)
D1P10T1	Laminar		
D2P8T1	Laminar		

TABLE 7 Task 2 Tests - Summary of Permeability Measurements

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Permeability Values (Darcys) along Proprotional Unloading- Reloading Stress Path

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3187	2687	2187	1687	1187	687	1187	1687	2187	2687	3187	3687	4187	Permeability Change at Failure Envelope (Darcys)
B2P7T2	Lower Sand	--------	0.389	0.312	0.275	0.252	0.204	0.125	0.355	0.263	0.317	0.200	0.270	0.308	----------
C1P4T2	Lower Sand	2.098	1.020	0.718	0.534	0.426	0.586	0.476	0.321	0.220	0.170	0.153	0.122	0.118	-0.18
D1P9T2	Lower Sand	2.069	1.965	1.799	1.659	1.471	1.245	0.611	0.482	0.382	0.311	0.284	0.226	0.209	-0.41

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3104	2604	2104	1604	1104	604	604	1104	1604	2104	2604	3104	3604	4104	Permeability Change at Failure Envelope (Darcys)
B2P3T2	Upper Sand	0.0400	0.0475	0.0492	0.0356	0.0278	0.0978		--------	0.0790	--------	0.0646	0.0615	--------	0.0686	----------
B2P1T2	Upper Sand	0.00208	0.00215	0.00280	0.00288	0.00347	0.00333		0.00059	0.00033	0.00007	----------				-0.0024
C1P2T2	Upper Sand	1.799	1.774	1.689	1.582	1.474	1.365		0.794	0.731	0.599	0.473	0.428	0.337	0.337	-0.46
C3P2T2	Upper Sand	2.321	2.271	2.214	2.146	2.013	1.881		1.343	1.101	0.898	0.636	0.475	0.333	0.255	0.03
C3P3T2	Upper Sand	0.03395	0.01981	0.0185	0.01378	0.01979	0.01312	0.02728	0.02424	0.01057	0.01052	0.0178	0.01623			0.0141
cycle 2	Upper Sand		0.01496	0.01198	0.01243	0.01149	0.01574	0.02379	0.01922	0.01566	0.01442	0.01491	0.0137			0.0012
cycle 3	Upper Sand		0.01174	0.01218	0.01242	0.01253	0.01277	0.00931	0.0176	0.01703	0.01687	0.01571	0.01474	0.01005	0.01168	0.0032
D1P7T2	Upper Sand															
D2P4T2	Upper Sand															

August 14, 1990

TABLE 8 Task 2 Tests - Summary of Porosity Measurements

892-2082

Porosity Values (%) along Proprotional Unloading- Reloading Stress Path

Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3187	2687	2187	1687	1187	687	1187	1687	2187	2687	3187	3687	4187	Porosity Change at Failure Envelope (%)
B2P7T2	Lower Sand	---	---	---	---	---	---	---	---	---	---	---	---	---	---
C1P4T2	Lower Sand	37.54	37.61	37.66	37.73	37.84	37.95	39.73	39.36	39.05	38.82	38.64	38.47	38.30	2.18
D1P9T2	Lower Sand	42.20	42.27	42.43	42.54	42.66	42.83	43.97	43.79	43.53	43.34	43.19	43.04	42.89	1.16

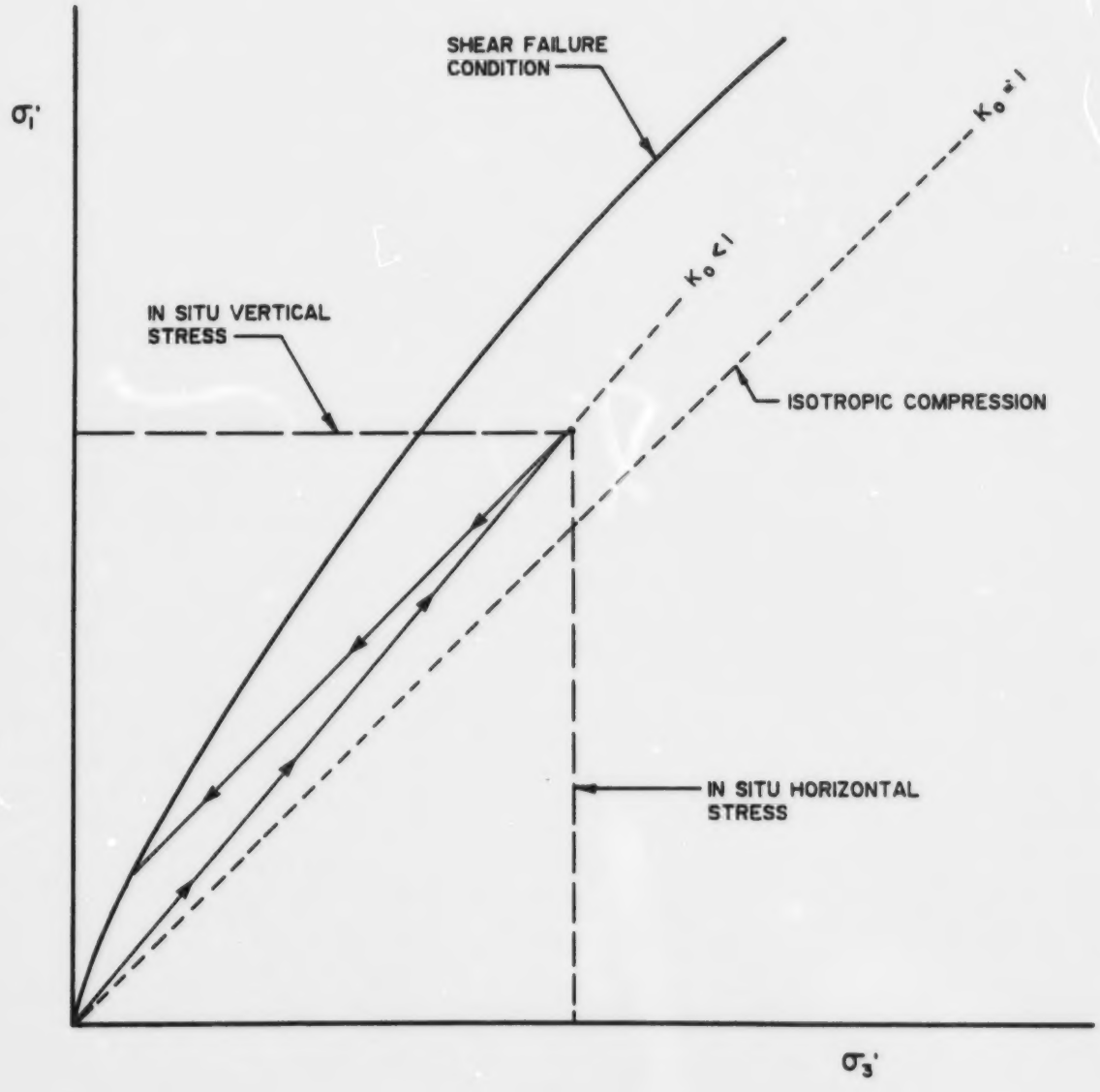
Sample Number	Geological Unit	Effective Lateral Confining Stress (MPa) 3104	2604	2104	1604	1104	604	1104	1604	2104	2604	3104	3604	4104	Porosity Change at Failure Envelope
B2P3T2	Upper Sand	41.03	41.09	41.16	41.23	41.33	41.50	41.37	41.23	-------	40.99	40.88	-------	40.68	---
B2P1T2	Upper Sand	33.12	33.12	33.12	33.19	33.27	33.40	35.49	35.24	35.04	---	---	---	---	---
C1P2T2	Upper Sand	42.16	42.19	42.26	42.36	42.50	42.67	44.36	44.04	43.75	43.52	43.32	43.14	42.97	2.83
C3P2T2	Upper Sand	36.88	36.91	36.97	37.03	37.12	37.26	38.52	38.29	38.08	37.90	37.76	37.64	37.52	2.34
C3P3T2	Upper Sand	42.93	43.02	43.07	43.14	43.22	43.36	45.37	45.07	44.83	44.65	44.5			1.43
C3P3T2	cycle 2		44.55	44.65	44.73	44.83	44.98	45.22	45.05	44.90	44.77	44.64			2.42
C3P3T2	cycle 3		44.69	44.75	44.83	44.92	45.08	45.49	45.31	45.15	45.02	44.91	44.78	44.68	0.34
D1P7T2	Upper Sand														0.52
D2P4T2	Upper Sand														

TABLE 9 Task 3 Tests - Summary

Sample Number	Geological Unit	Effective Confining Stress (MPa)	Back Pressure (MPa)	Deviator Stress at Failure (MPa)	Axial Strain at Failure (%)	Volumetric Strain at Failure (%)	Young's Modulus (MPa)	Maximum Dilation (%)
B:1P8T3	Lower Sand	0.500	4.500	1.890	3.61	0.92	110.61	4.86
C:1P4T3	Lower Sand	1.000	4.000	3.760	5.83	0.89	138.36	4.20
D:2P6T3	Lower Sand							
B:2P7T3	Lower Sand	0.200	4.000	0.930	2.77	1.65	70.92	2.99
B:1P4T3	Upper Sand	0.500	5.000	2.840	3.35	1.35	104.63	3.93
C:1P2T3	Upper Sand	1.000	4.000	3.050	4.77	0.14	190.13	0.50
C:3P2T3	Upper Sand	0.500	4.000	2.470	2.05	1.40	212.89	7.16
C:3P2T3	cycle 2						223.24	
C:3P2T3	cycle 3						208.94	
D1.P7T3B	Upper Sand	0.200	4.000	-0.210	-1.75	0.42	29.82	3.84
D:1P7T3	Upper Sand	0.200	4.000	1.000	3.80	1.20	43.79	3.67
D1.P7T3C	Upper Sand	1.000	4.000	-4.370	-4.63	-0.96	1076.76	-0.82
D2:P4T3B	Upper Sand	0.750	4.000	-0.560	-4.74	1.52	257.98	1.88
D:2P4T3	Upper Sand	0.750	4.000	3.010	5.38	0.81	107.13	4.41
D2:P4T3C	Upper Sand	0.500	4.000	-3.100	-6.34	0.71	604.05	1.10
B:2P3T3	Upper Sand	0.200	4.000	0.490	5.51	2.17	43.33	5.23
B:2P1T3	Upper Sand	1.000	4.000	3.590	4.12	0.49	289.45	1.70
D2:P8T3T	Laminar	0.500	4.000	2.210	1.90	0.59	153.39	2.86
D2:P8T3B	Laminar	0.500	4.000	1.960	2.50	0.66	119.61	2.82
D:2P8T3	Laminar	0.200	4.000	1.120	2.34	1.32	78.75	3.87
D1.P10T1	Laminar	0.200	4.000	1.600	0.78	0.91	207.00	2.93
D1.P10T3	Laminar	1.000	4.000	4.220	2.05	0.39	306.55	2.25
B:1P2T3	Shale							
B:1P7T3	Shale	0.200	4.000	2.820	3.05	0.55	105.74	1.71
C:1P1T3	Shale	0.500	4.000	3.200	2.32	-0.65	159.91	0.50
D:2P1T3	Shale	1.000	4.000	7.570	1.94	0.20	452.71	1.22
D:1P3T1	Clasts	0.200	1.000	0.790	3.02	1.04	69.92	2.07
D:1P3T1	cycle 2		1.000	0.760	6.60	1.35	72.11	1.91
D:1P3T1	cycle 3		1.000	0.650	10.85	1.09	70.88	1.50
D:1P3T2	Clasts	1.000	1.000	5.960	2.40	0.30	286.56	1.61
D:1P3T2	cycle 2		1.000	3.450	6.02	0.85	412.8	1.23
D:1P3T2	cycle 3		1.000	3.310	11.12	0.85	470.56	1.14

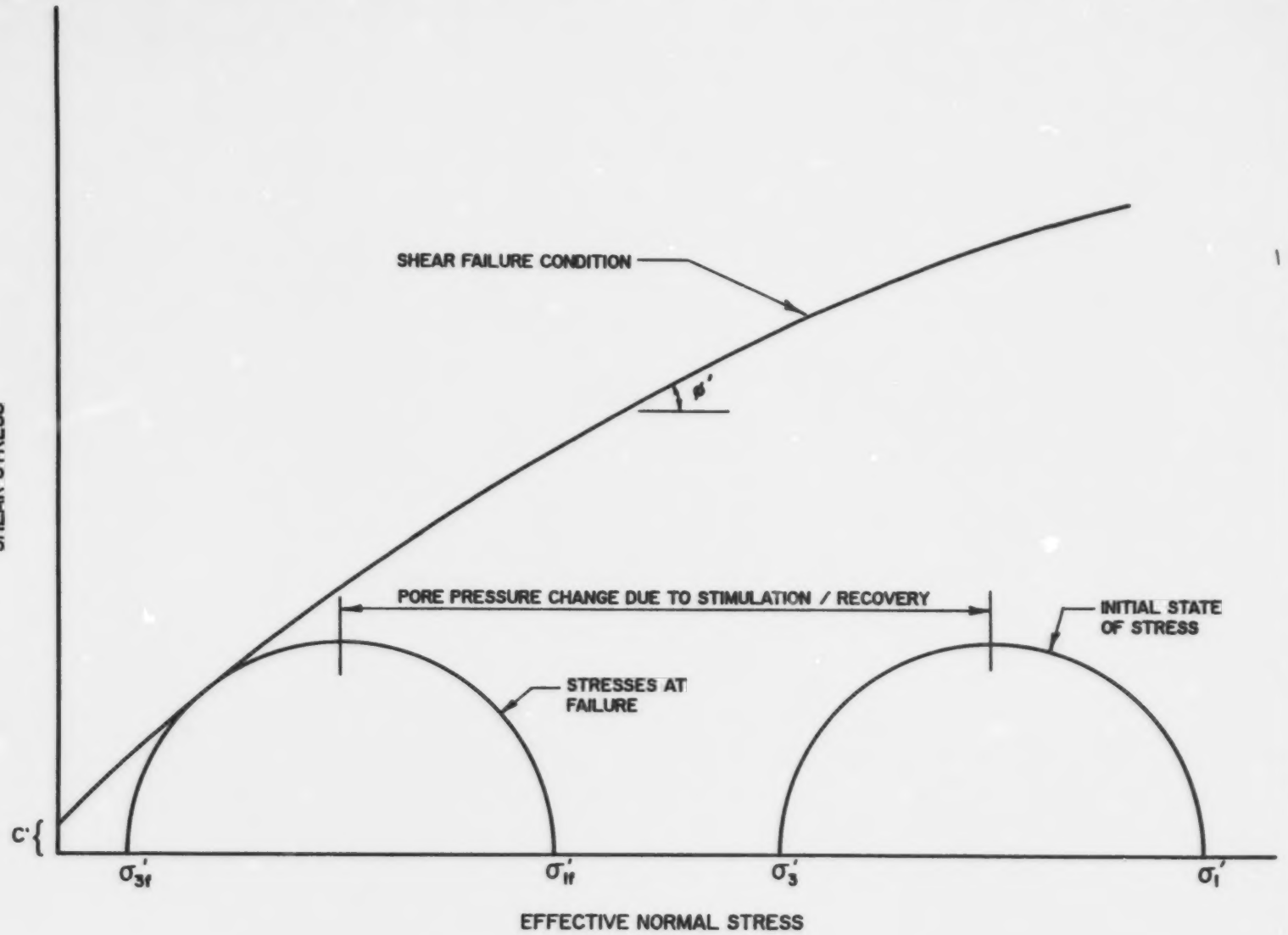
STRESS PATH FOR TASK 1 TESTS

Figure 1



PROJECT No. 892-20828 DRAWN CG REVIEWED KnK DATE OCT 90

PROJECT No. 892-2082B DRAWN RK REVIEWED KMK DATE SEP 90



MOHR - COULOMB REPRESENTATION OF TASK 1 TESTS

Figure 2

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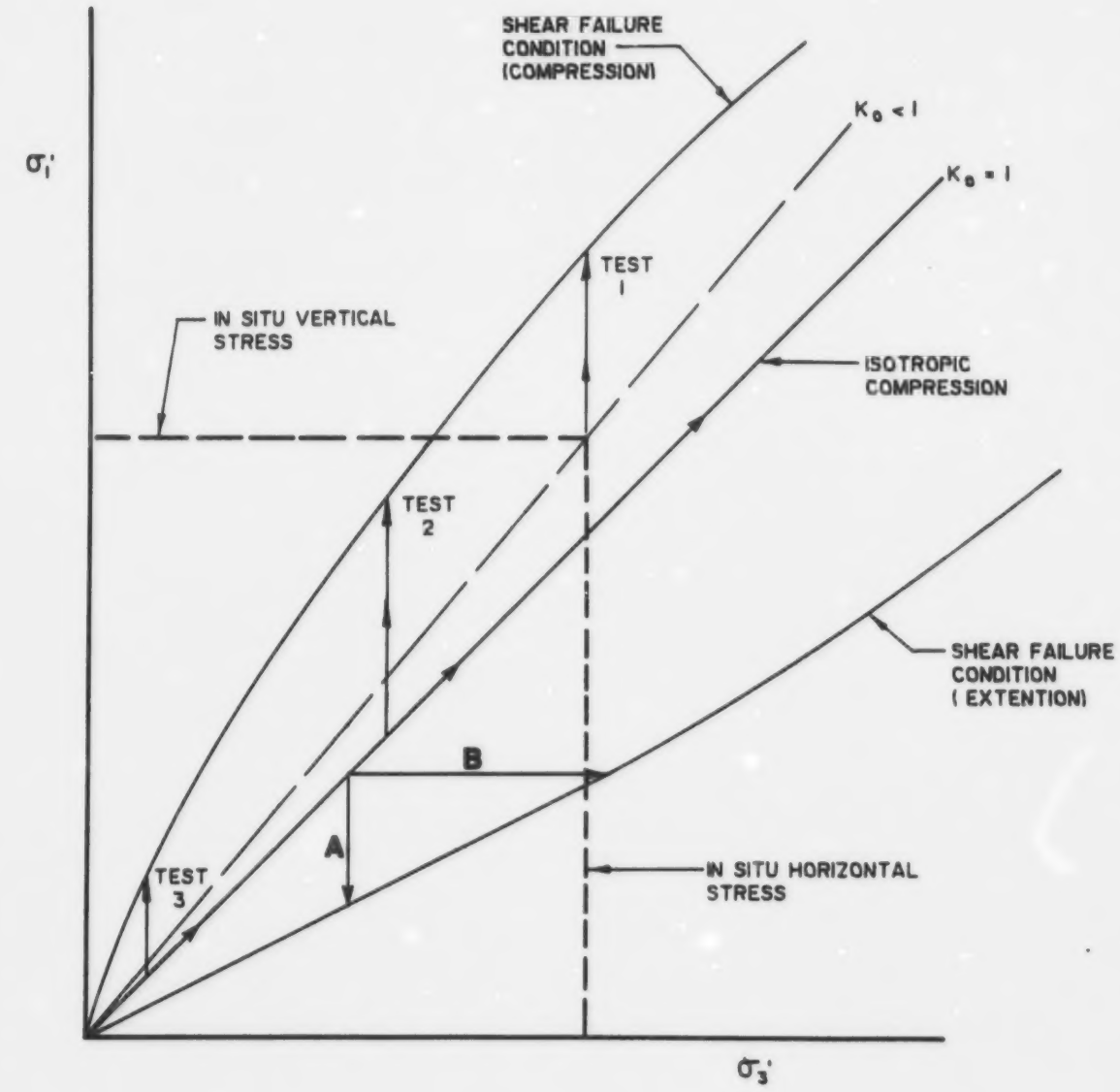
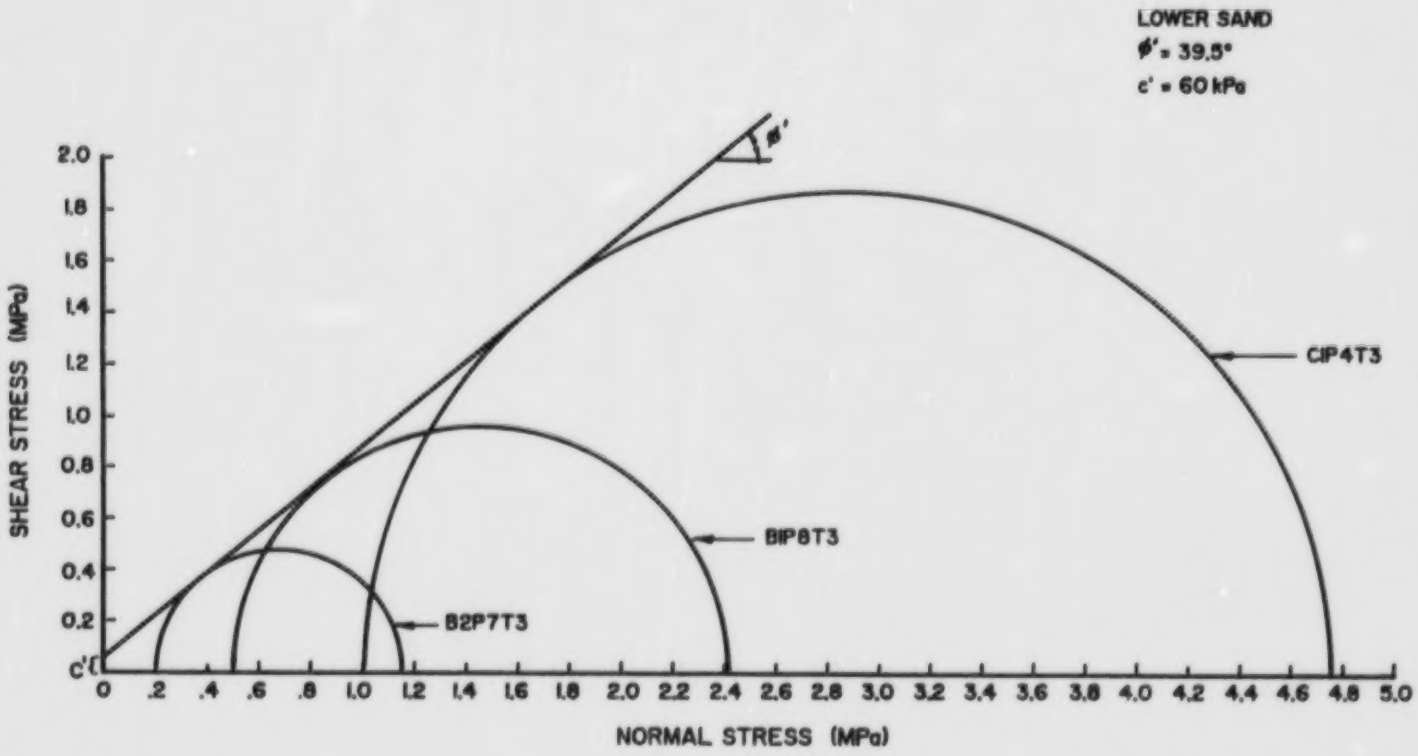
STRESS PATHS FOR TASK 3 TESTS

Figure 3



PROJECT No. 892-2062B DRAWN CG REVIEWED KMK DATE SEPT 90

PROJECT No. 892-20628 DRAWN RK REVIEWED KWK DATE SEP 90



SHEAR FAILURE ENVELOPE FOR LOWER SAND UNIT

Figure 4

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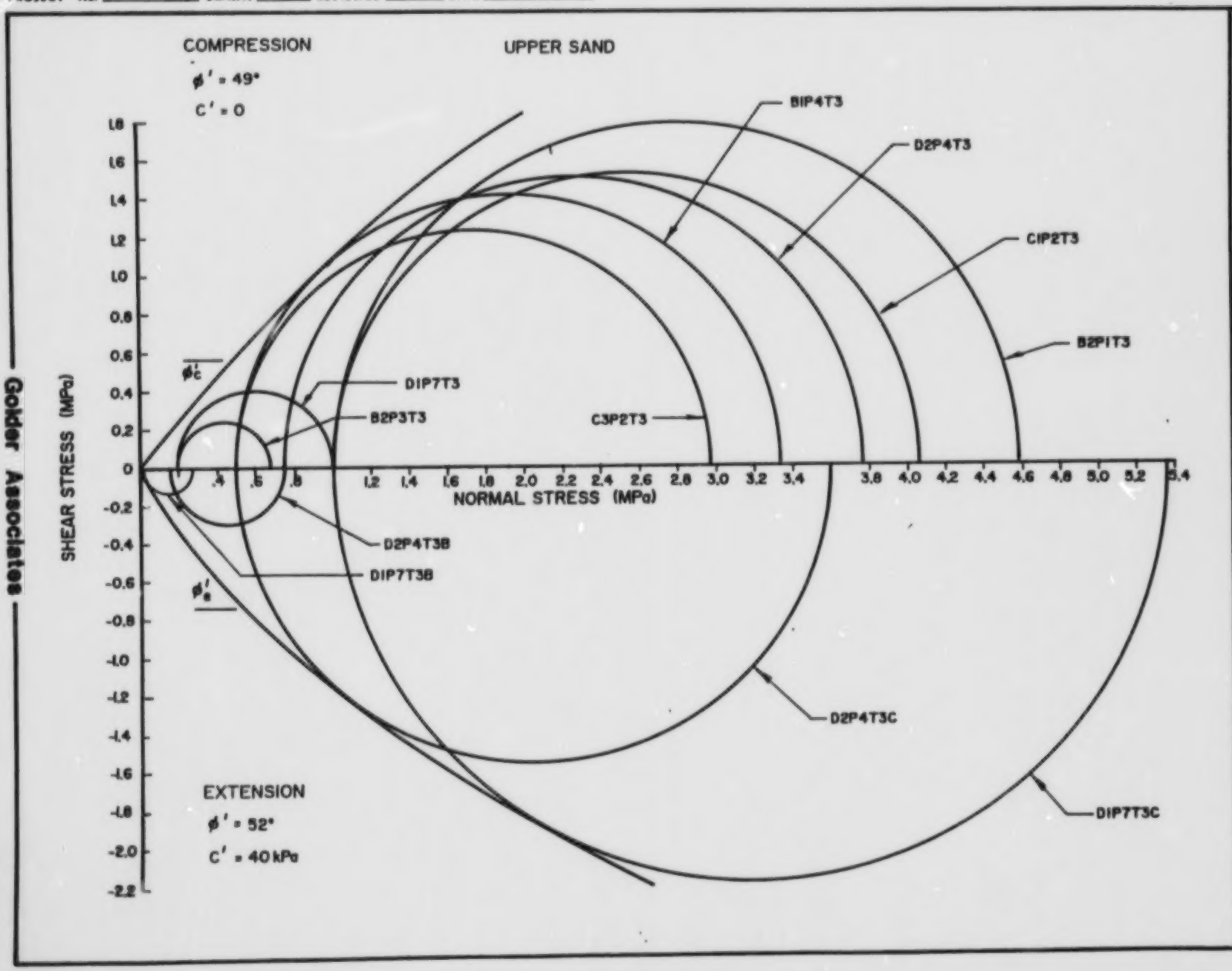
PROJECT No. 892-2082B DRAWN RK REVIEWED KMK DATE OCT 90



SHEAR FAILURE ENVELOPES FOR UPPER SAND UNIT

Figure 5

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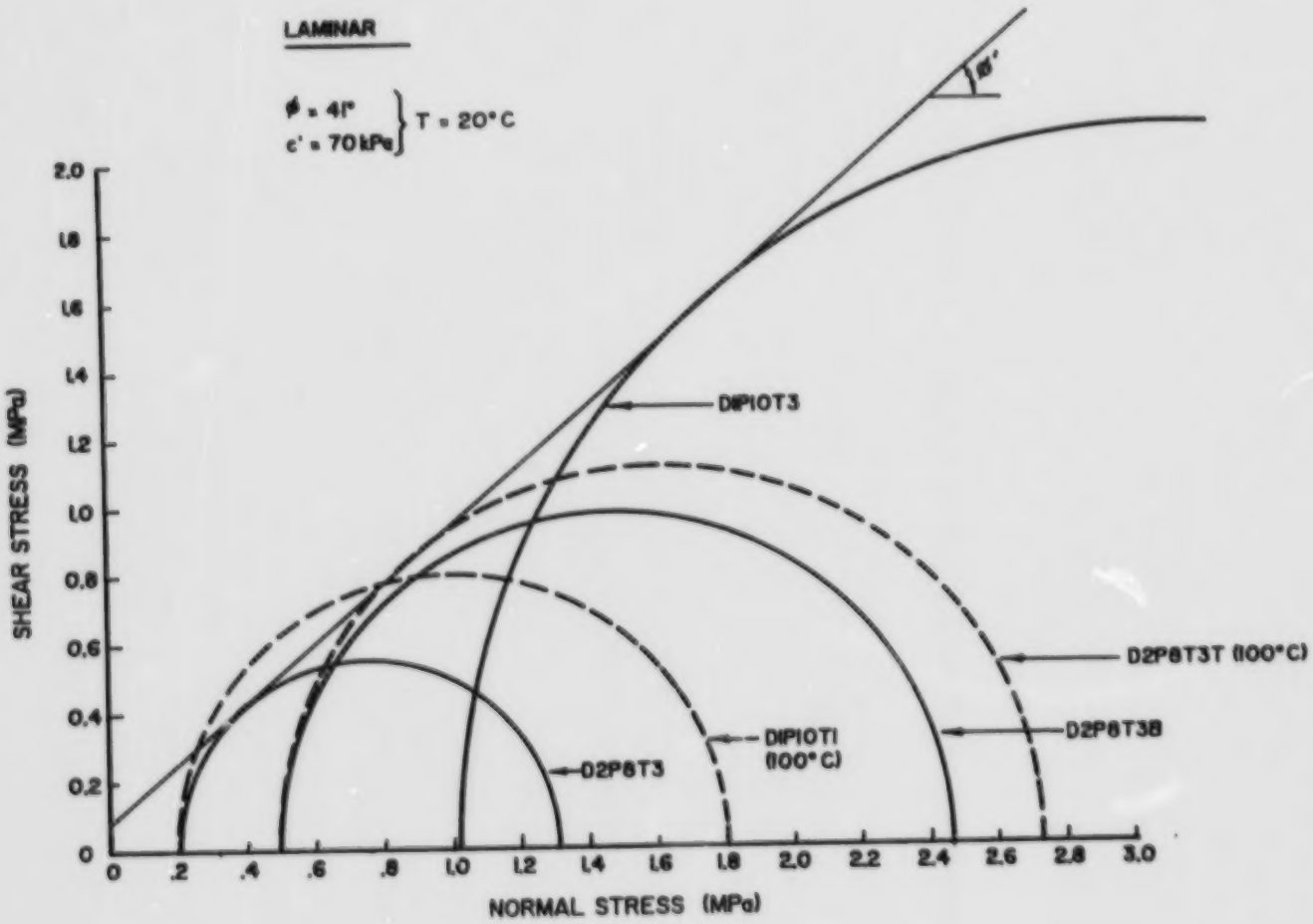
PROJECT No. 892-20825 DRAWN RK REVIEWED KMK DATE SEP 90



SHEAR STRENGTH OF LAMINAR SPECIMENS

Figure 6

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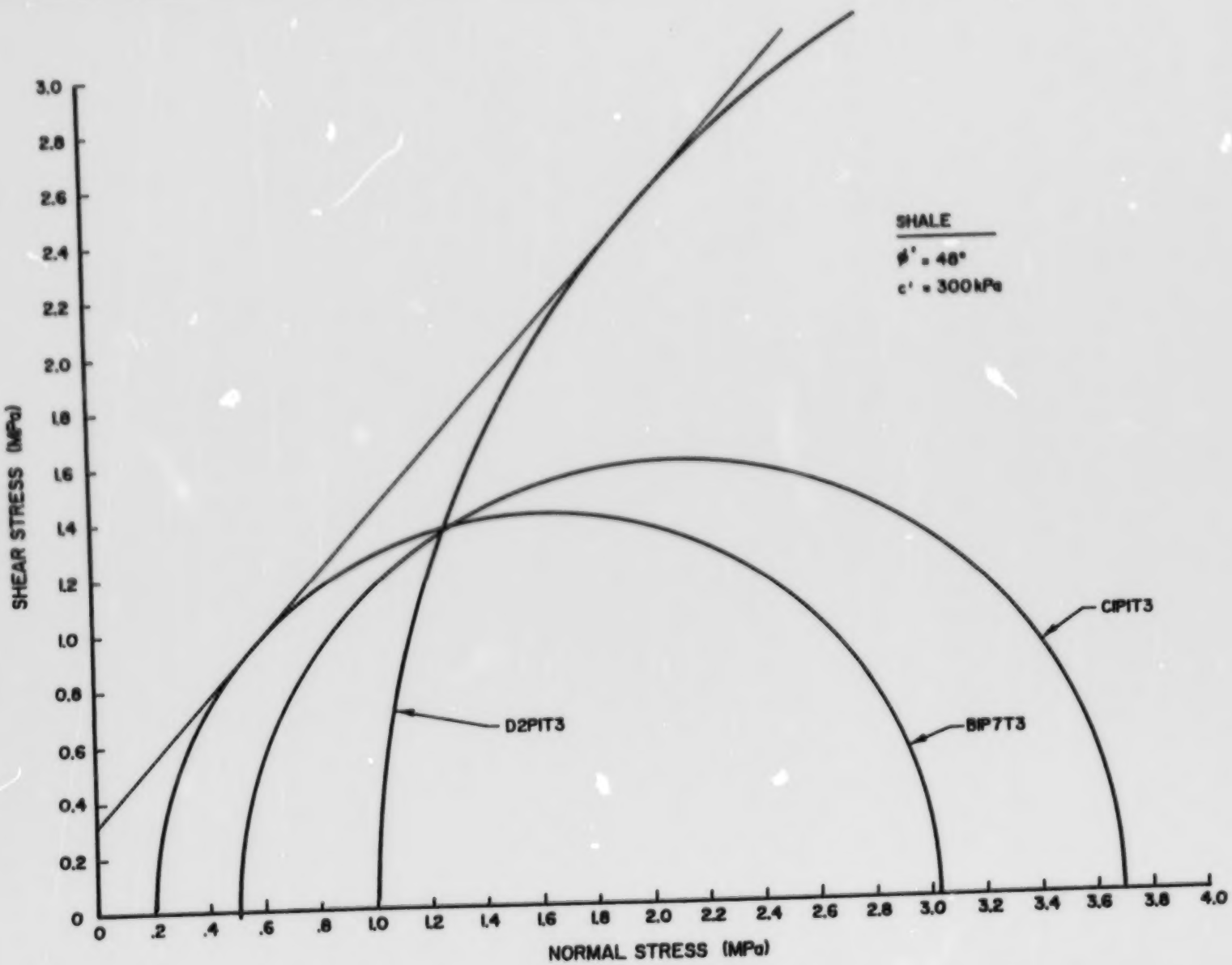
PROJECT No. 892-20828 DRAWN RK REVIEWED RMK DATE SEP 90



SHEAR STRENGTH OF McMURRAY FORMATION SHALE

Figure 7

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APPENDIX I - TEST PROCEDURES

Task 1 - Measurement of Geotechnical Properties

Testing Procedure:

1. Machine frozen sample to correct dimension in cold room. Measure density.
2. Mount sample and assemble apparatus in cold room.
3. Measure bitumen, water and solids content from trimmings.
4. Apply nominal vertical, horizontal and sample fluid pressure (σ'_3 = 200 kPa).
5. Perform B test (σ' = 100 kPa) - Establish pore fluid saturation pressure.
6. Increase vertical and horizontal effective stress to in situ conditions maintaining u above pfsp.
7. Carry out cyclic compression test.
8. Rerun B test. Calculate final B value.
9. Measure E, c_b and e_v.
10. Increase u by 350 kPa. Keep σ_1, and σ_3 constant.
11. Measure E, c_b and e_v.
12. Repeat steps 10 and 11 to shear failure.
13. Decrease u by 350 kPa. Keep σ_1, and σ_3 constant.
14. Measure E, c_b and e_v.
15. Repeat steps 13 and 14 to two increments above in situ stress.
16. Unload sample.
17. Remove sample and freeze. Measure density and sketch failure mode.
18. Measure bitumen, water and solids content of entire sample.

Task 2 - Measurement of Fluid Flow Properties

Testing Procedure :

1. Machine frozen sample to correct dimensions in cold room. Measure density.
2. Mount sample and assemble apparatus in cold room.
3. Measure bitumen, water and solids content from trimmings.
4. Apply nominal vertical, horizontal and sample fluid pressure (σ'_3 = 200 kPa). Allow sample to thaw.
5. Flood sample with toluene lactone to solvent extract bitumen from sample.
6. Alternate soaking and flushing until all bitumen is removed.
7. Perform B test (σ'_3 = 100 kPa) - Establish pore fluid saturation pressure.
8. Increase vertical and horizontal effective stress to in situ conditions maintaining u above pfsp.
9. Carry out cyclic compression test.
10. Rerun B test. Calculate final B value.
11. Measure K.
12. Increase u by 350 kPa. Keep σ_1, and σ_3 constant.
13. Measure K.
14. Repeat steps 12 and 13 to shear failure.
15. Decrease u by 350 kPa. Keep σ_1, and σ_3 constant.
16. Measure K.
17. Repeat steps 15 and 16 to two increments above in situ stress.
18. Unload sample.
19. Remove sample and freeze. Measure density and sketch failure mode.

Task 3 - Measurement of Oil Sands Yield Criteria

Testing Procedure:

1. Machine frozen sample to correct dimensions in cold room. Measure density.
2. Mount sample and assemble apparatus in cold room.
3. Measure bitumen, water and solids content from trimmings.
4. Apply nominal vertical, horizontal and sample fluid pressure (σ'_3 = 200 kPa). Allow sample to thaw.
5. Perform B test (σ'_3 = 100 kPa) - Establish pore fluid saturation pressure.
6. Increase vertical and horizontal effective stress to in situ conditions maintaining u above pfsp.
7. Carry out cyclic compression test.
8. Rerun B test. Calculate final B value.
9. Reduce effective stress to desired level.
10. Perform passive drained triaxial compression test.
11. Unload sample.
12. Remove sample and freeze. Measure density and sketch failure mode.
13. Measure bitumen, water and solids content of entire sample.

APPENDIX II - TASK 1 TEST RESULTS

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: 01PST1

DEPTH: 316.75 - 317.10

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 1

DATE TEST COMPLETED: 30 January 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE:

04 and 05 Effective confining stress = 200 kPa

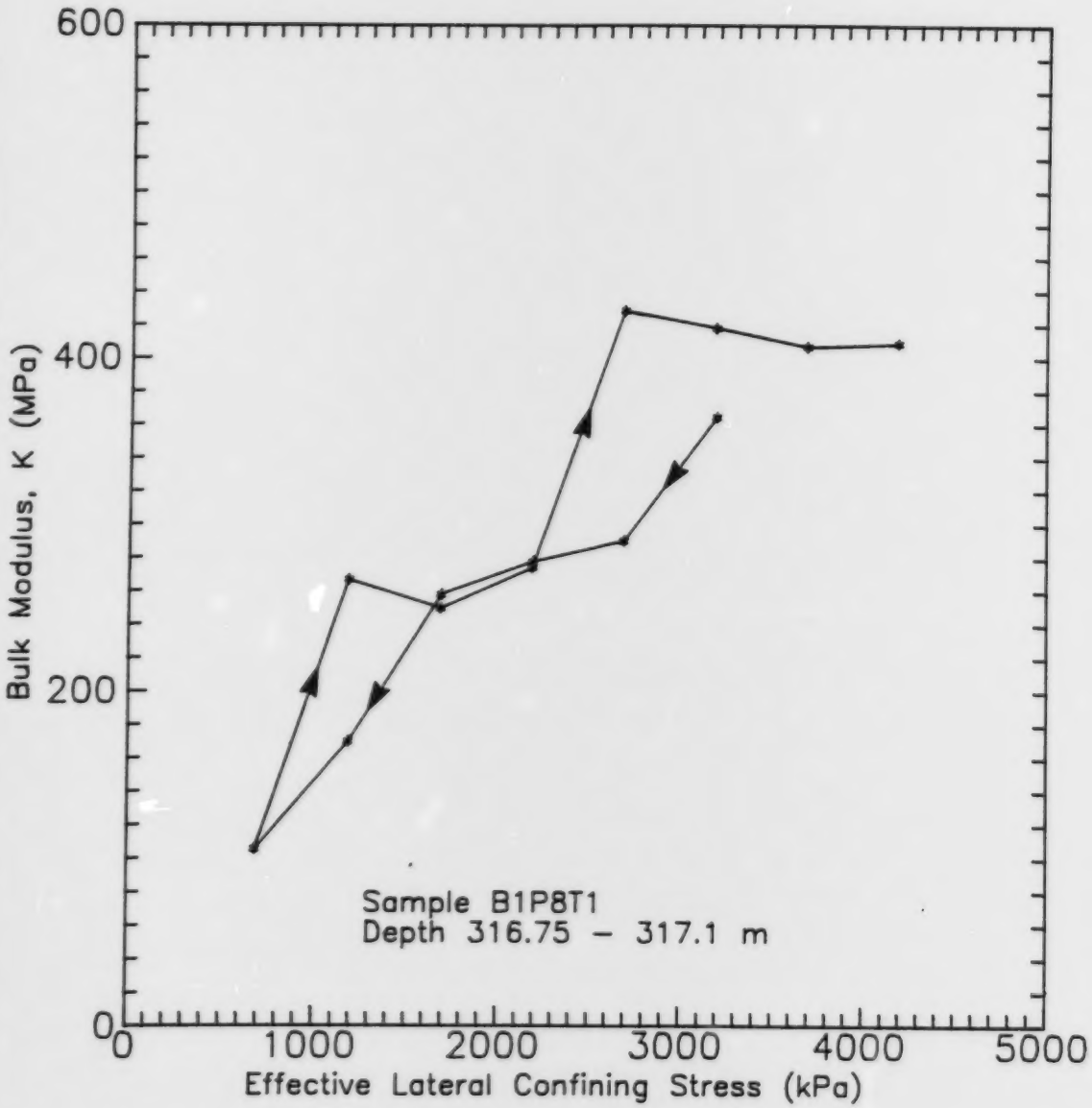
08 B test was not done after cyclic compression at in situ stresses

010 Back pressure was increased by 500 kPa in 250 kPa increments

016 Sample was subject to axial strain beyond peak strength (17 % axial strain)

REMARKS:

Figure

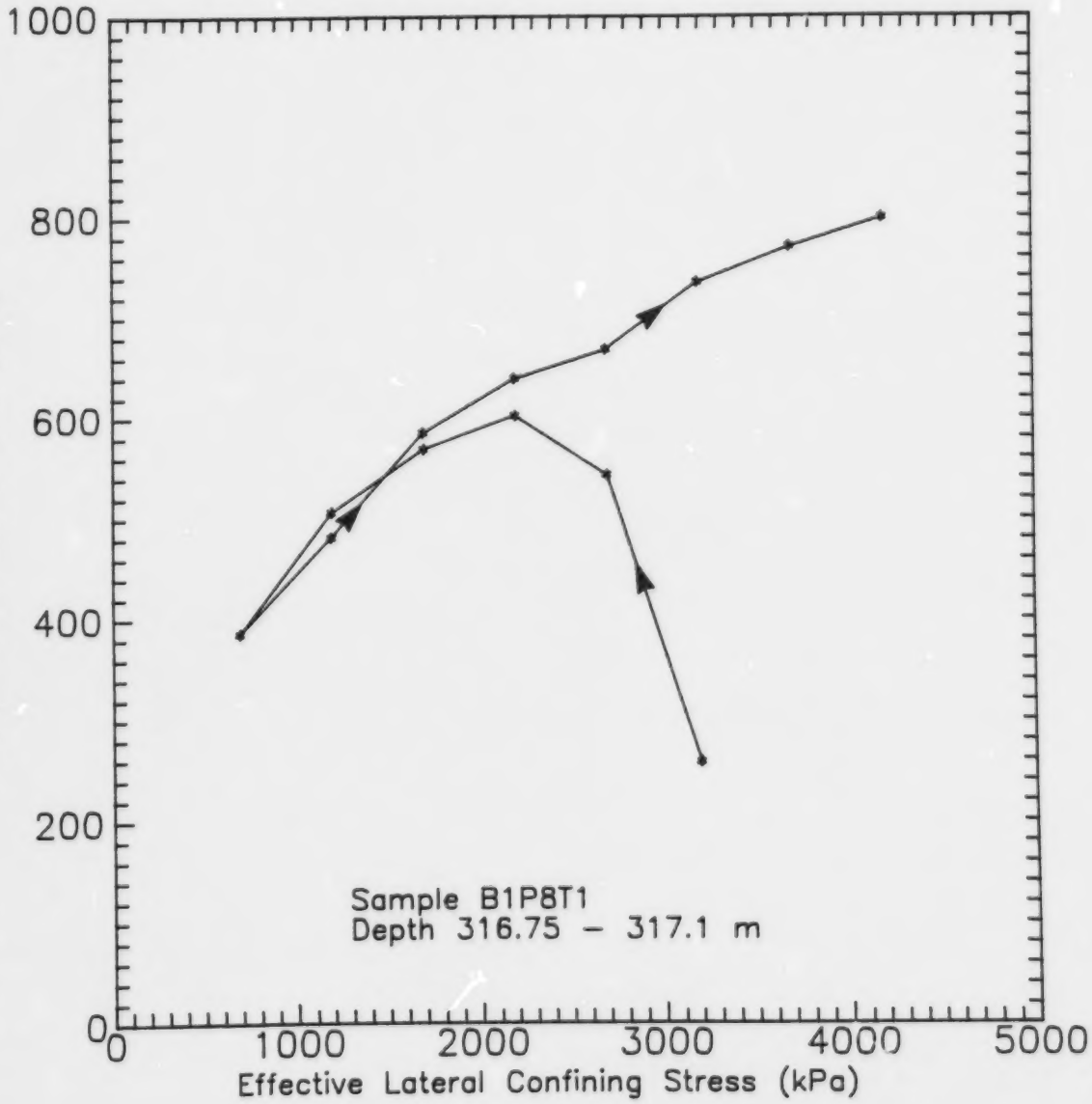


Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates

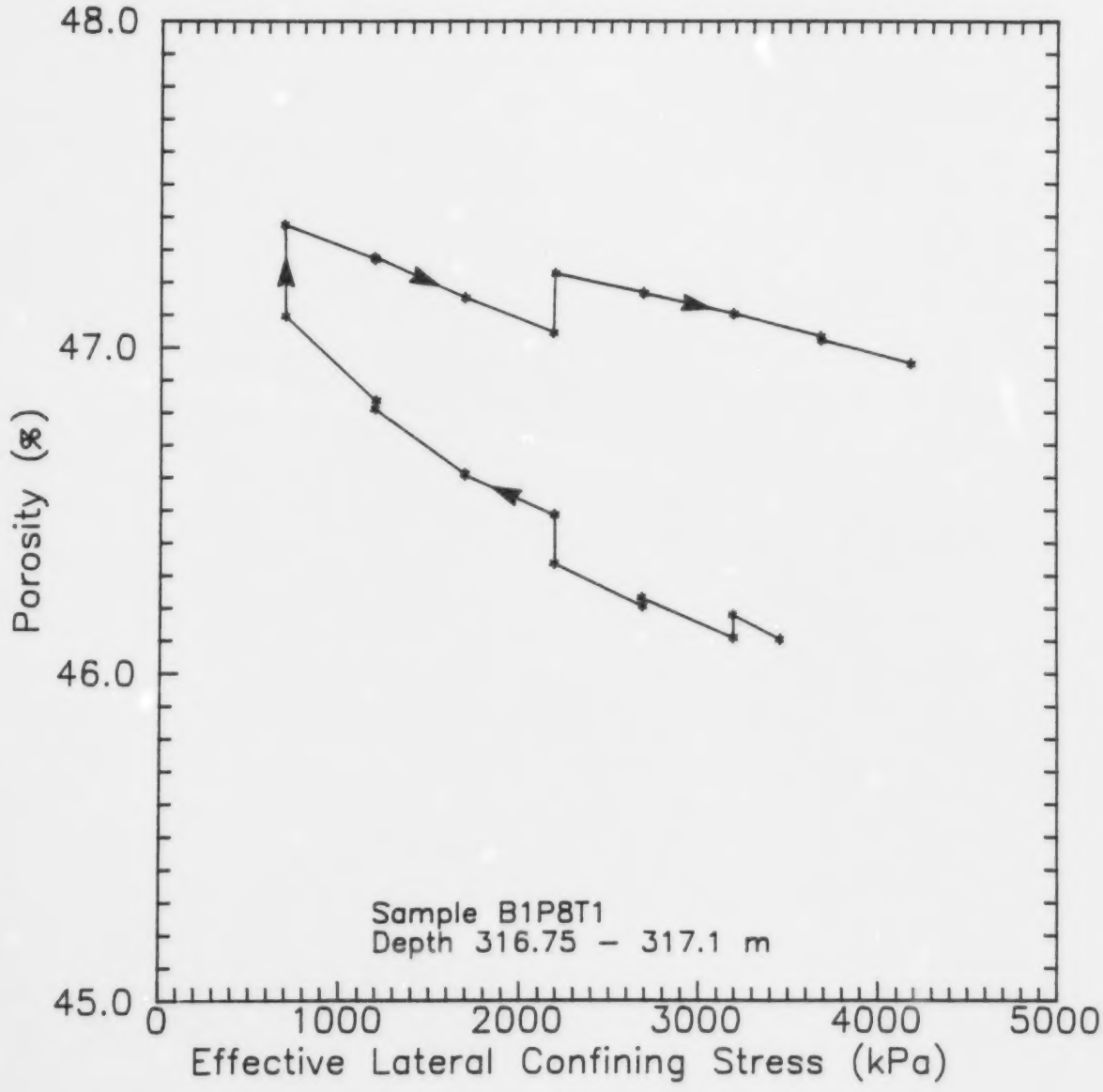
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: 02P7T1

DEPTH: 329.20 - 329.55 m

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 1

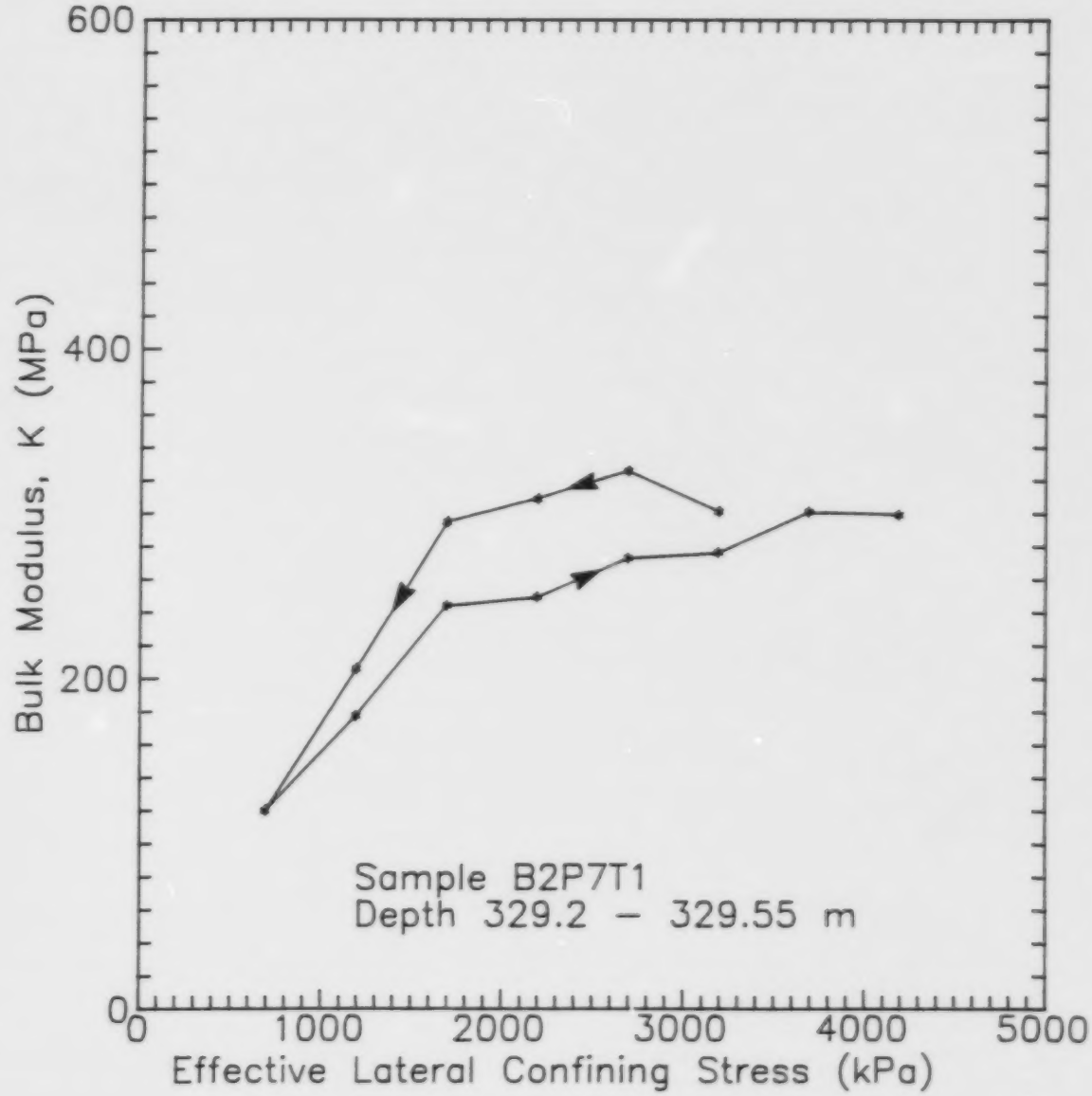
DATE TEST COMPLETED: 15 February 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 & 05 Effective Confining stress = 200 kPa

016 Prior to unloading the sample was strained to 15% axial strain

REMARKS:

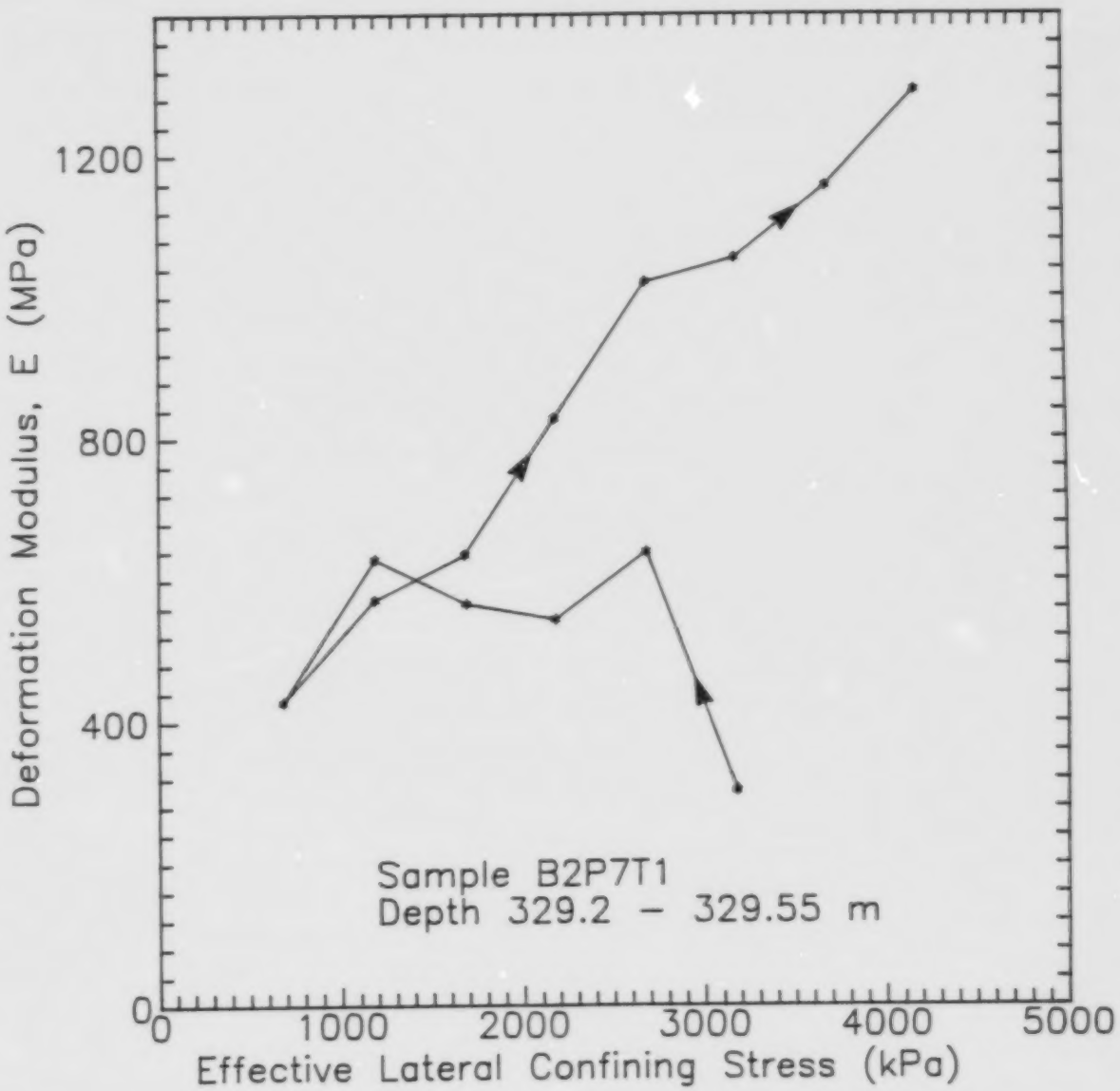
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

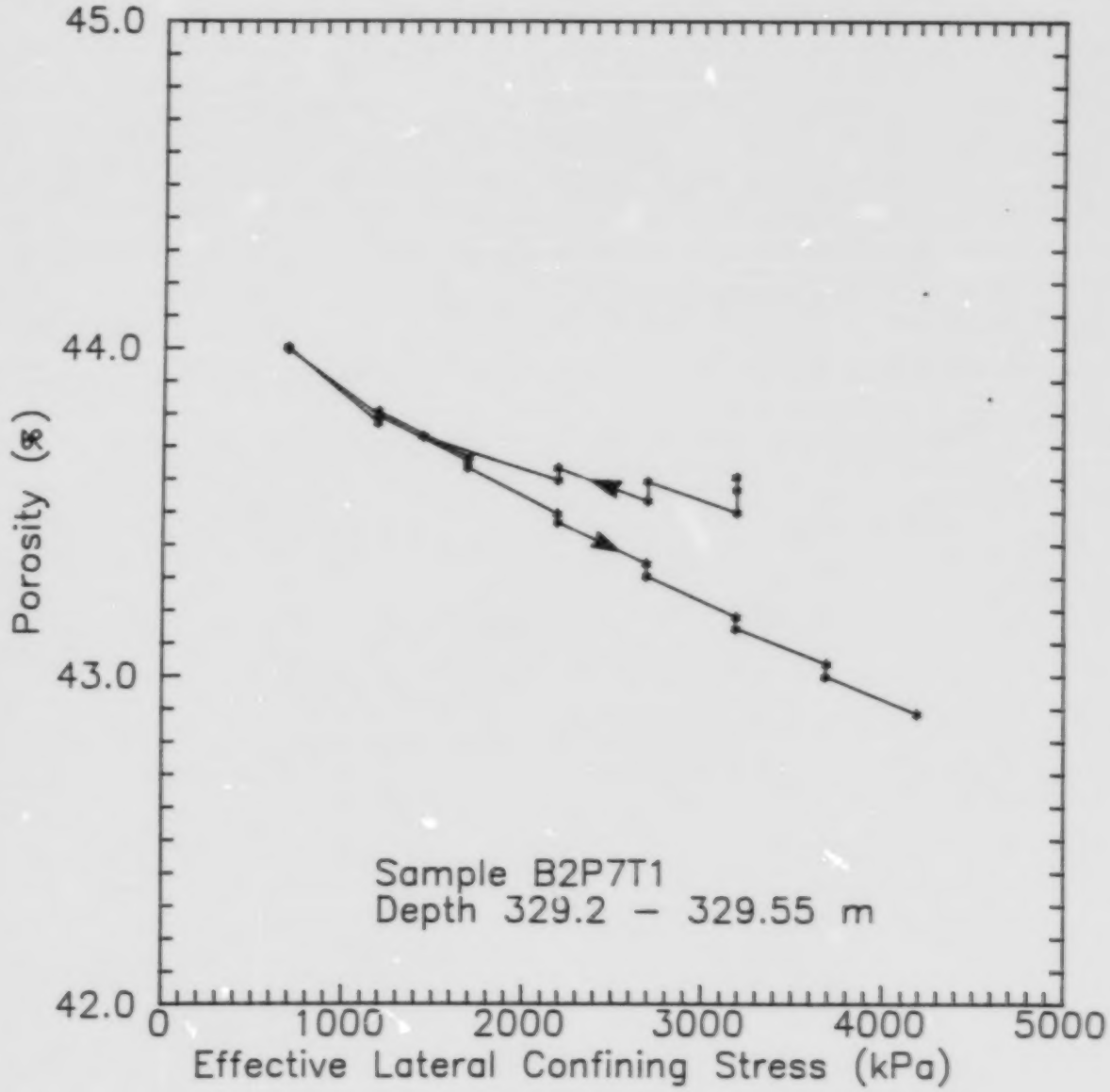
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: CIP4T1

DEPTH: 313.45 - 313.80 m

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 1 (Modified Procedure)

DATE TEST COMPLETED: 27 March 1990

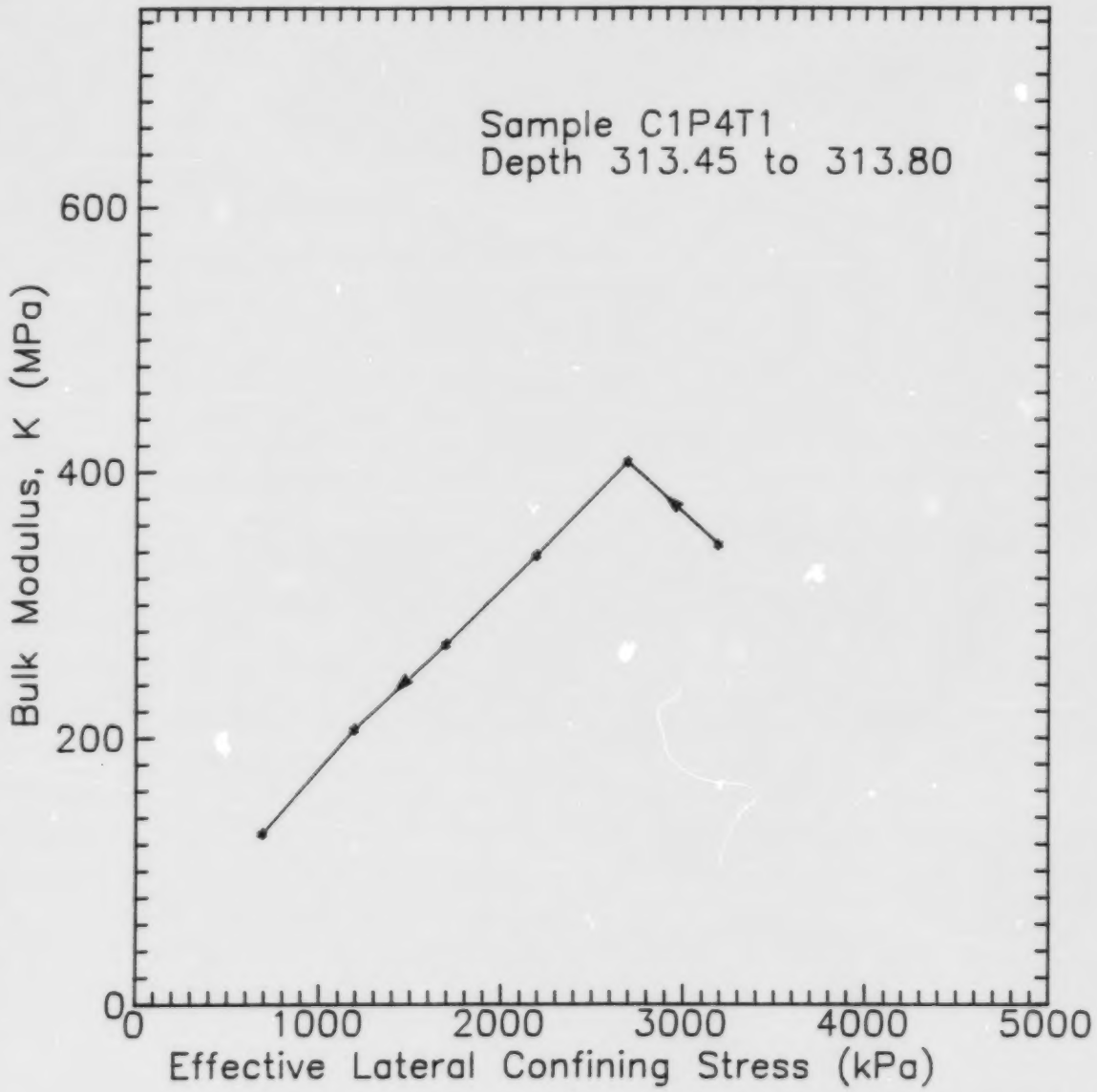
DEVIATIONS FROM STANDARD TEST PROCEDURE: 90 B test carried out at in situ stress prior to stress cycling. No B test Performed after cycling.

810 Back pressure was increased by 500 kPa in 250 kPa increments.

Sample was permitted to fail once reaching the shear failure envelope

REMARKS:

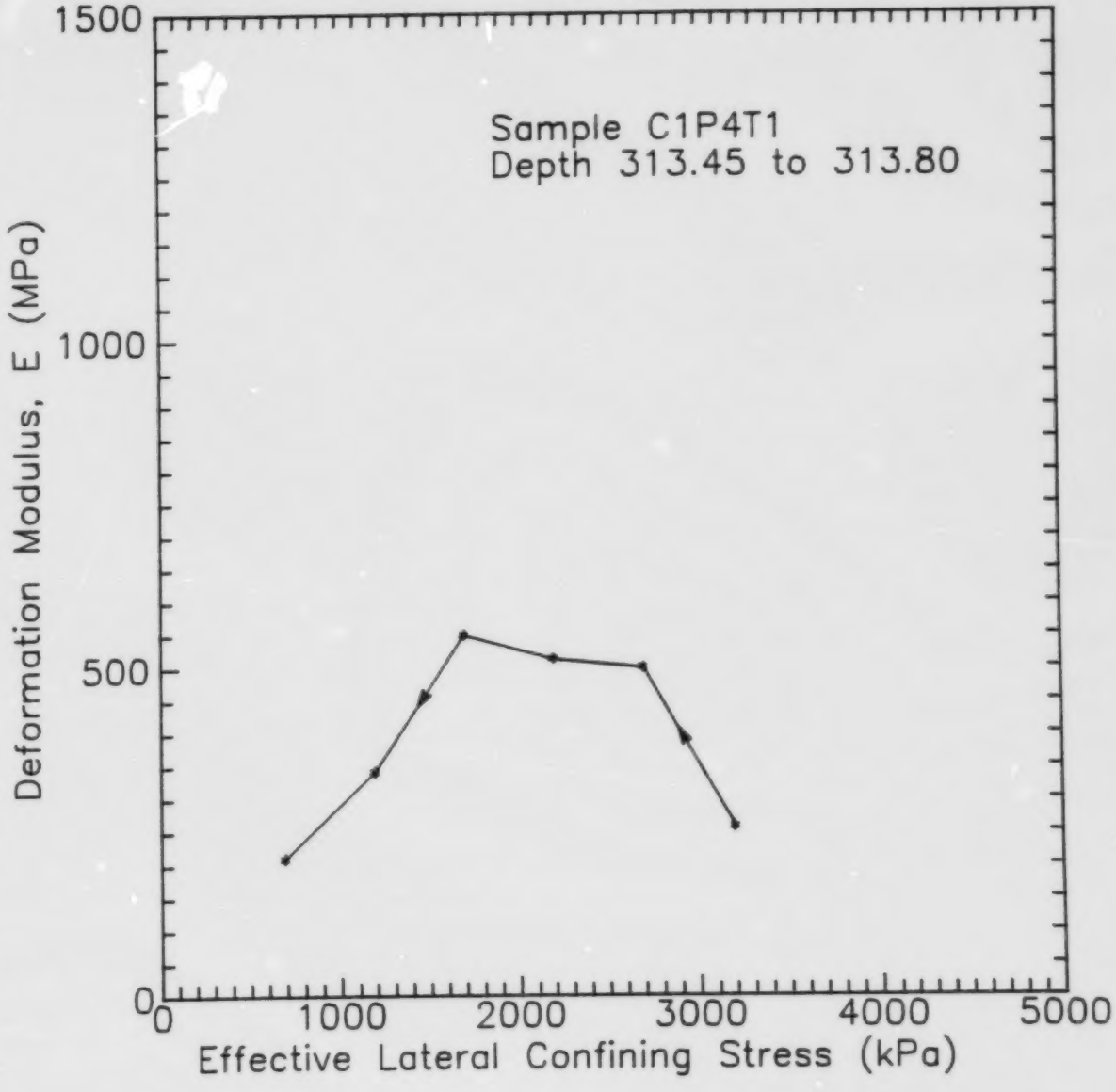
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure

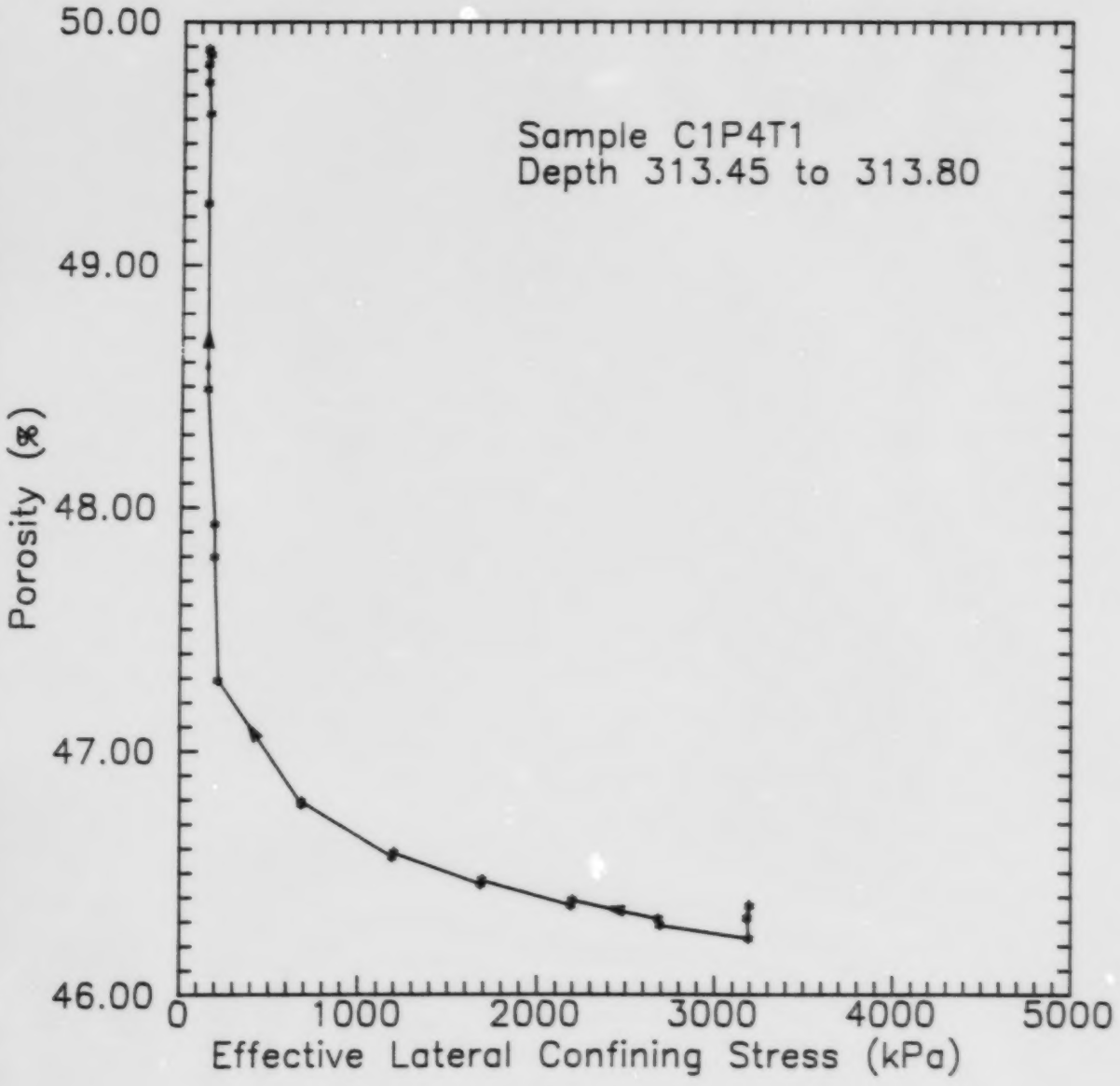


Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates

Figure

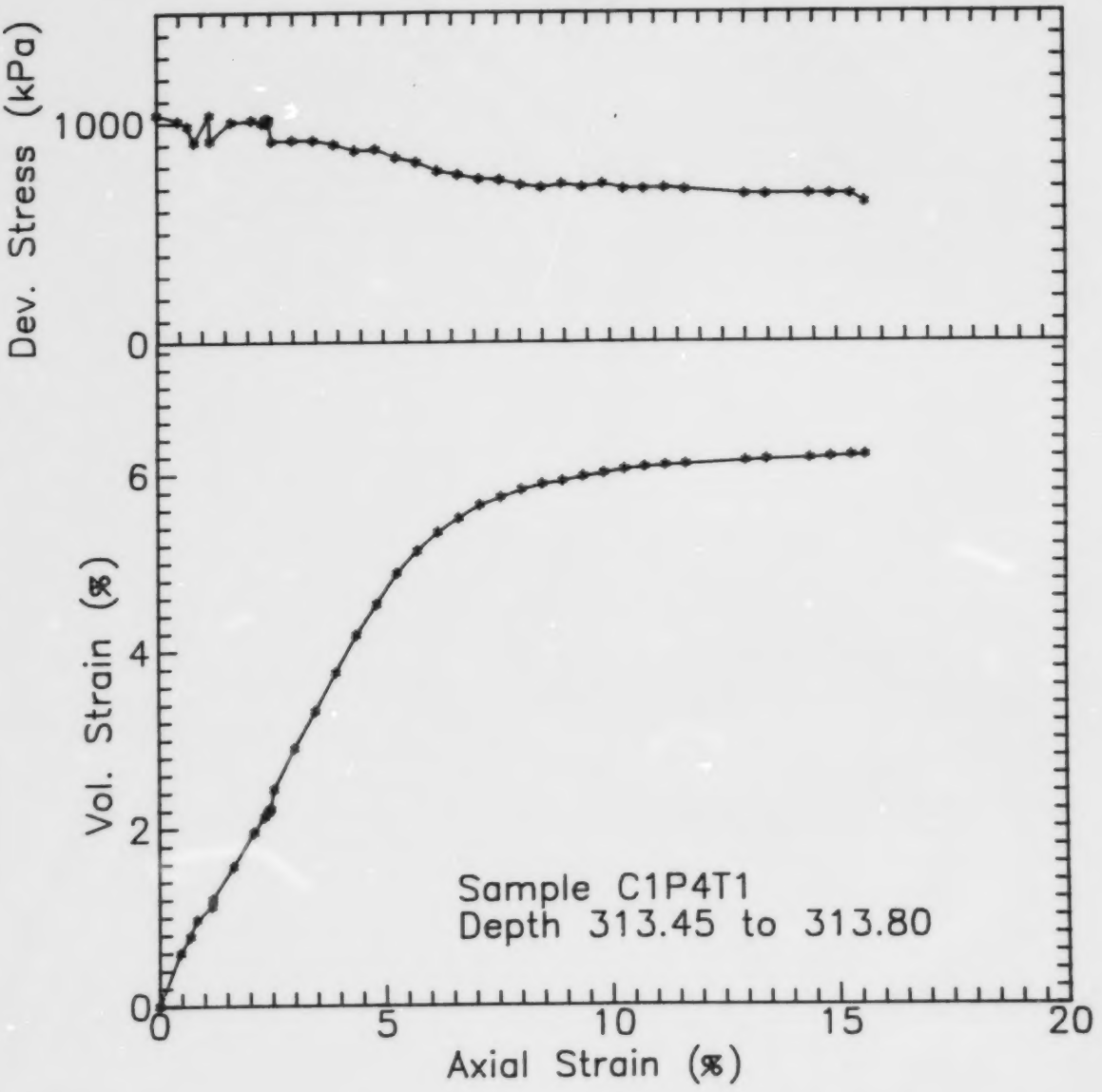


Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D2P6

DEPTH: 314.90 - 315.06

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Sand, Some sample disturbance apparent, Pitting was present on outside of sample

TYPE OF TEST: Task 1

DATE TEST COMPLETED: 23 May 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

05 Pore pressure increased to 4 MPa, then B test was carried out

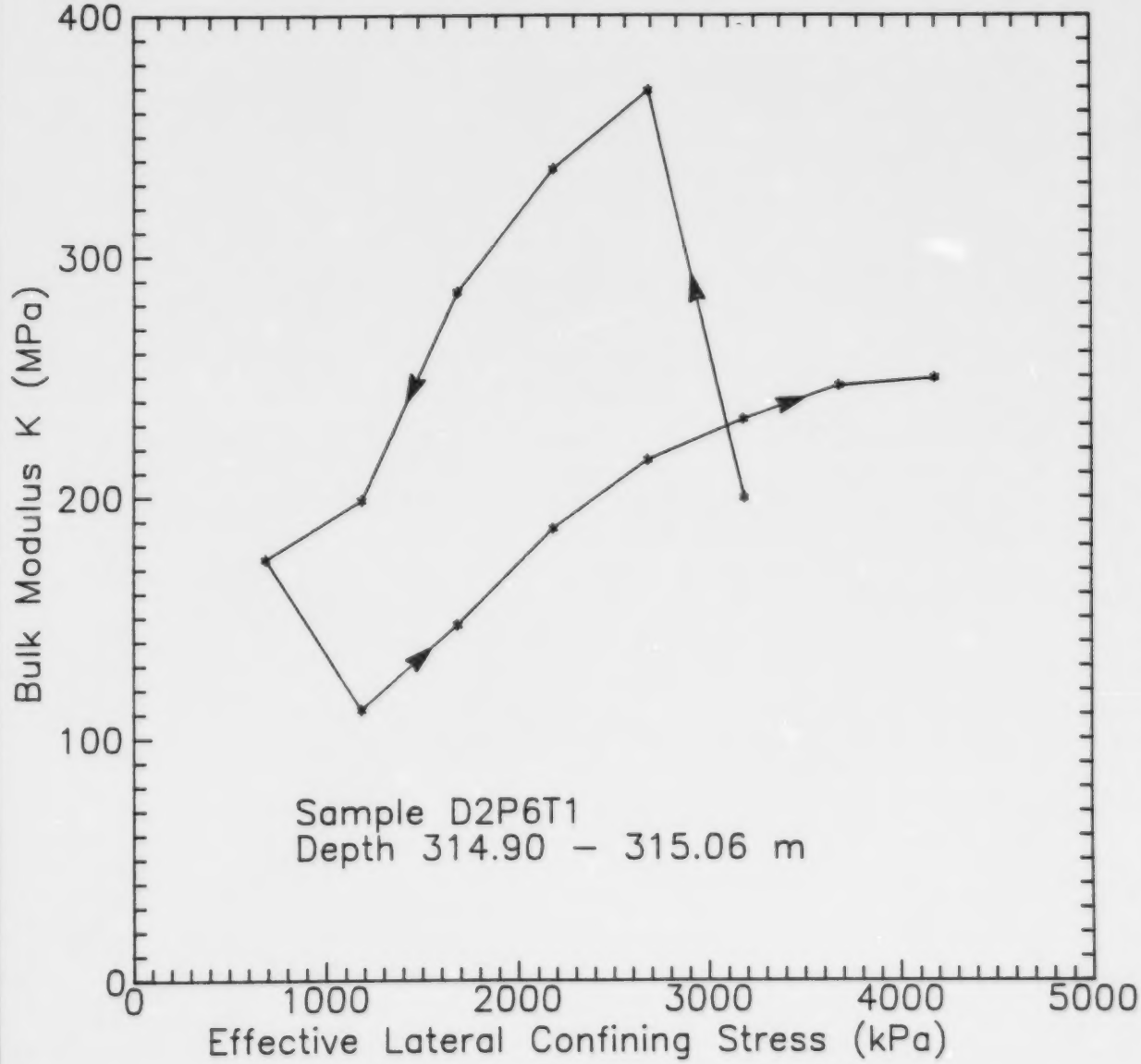
010 Pore pressure was increased by 500 kPa

012 Sample was strained 12% at failure envelope

013 Pore pressure was inceased by 500 kpa

REMARKS:

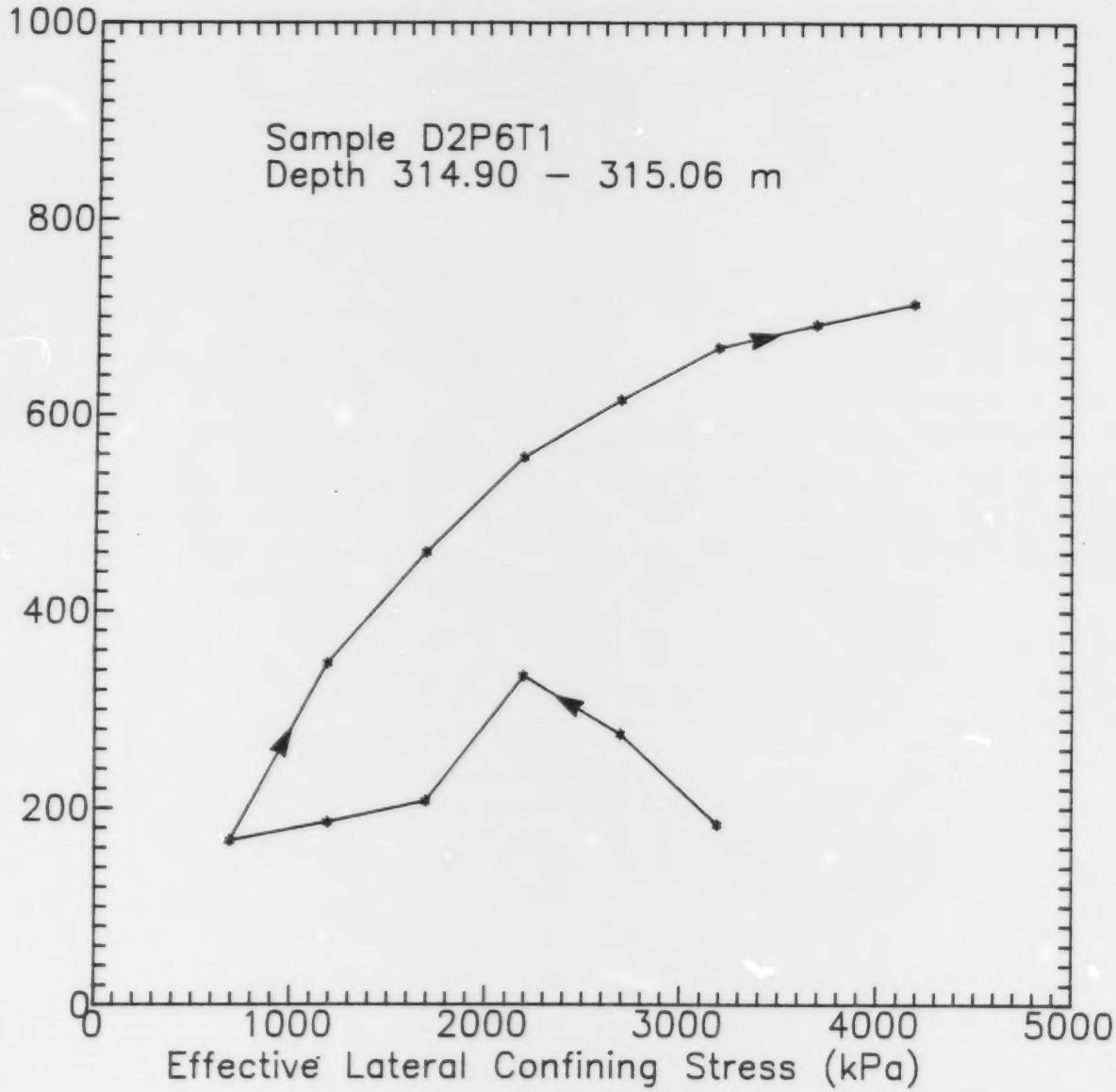
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

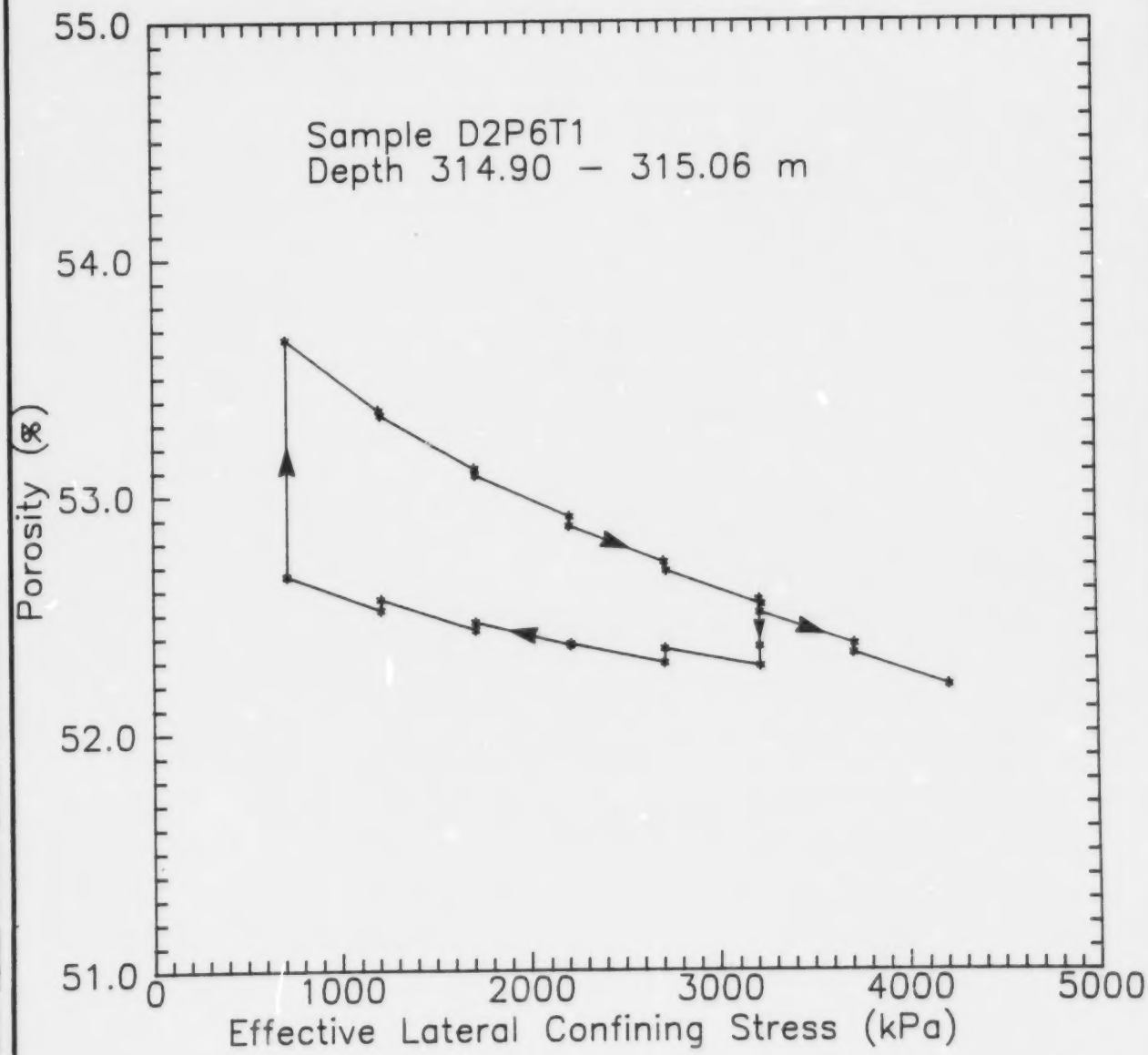
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

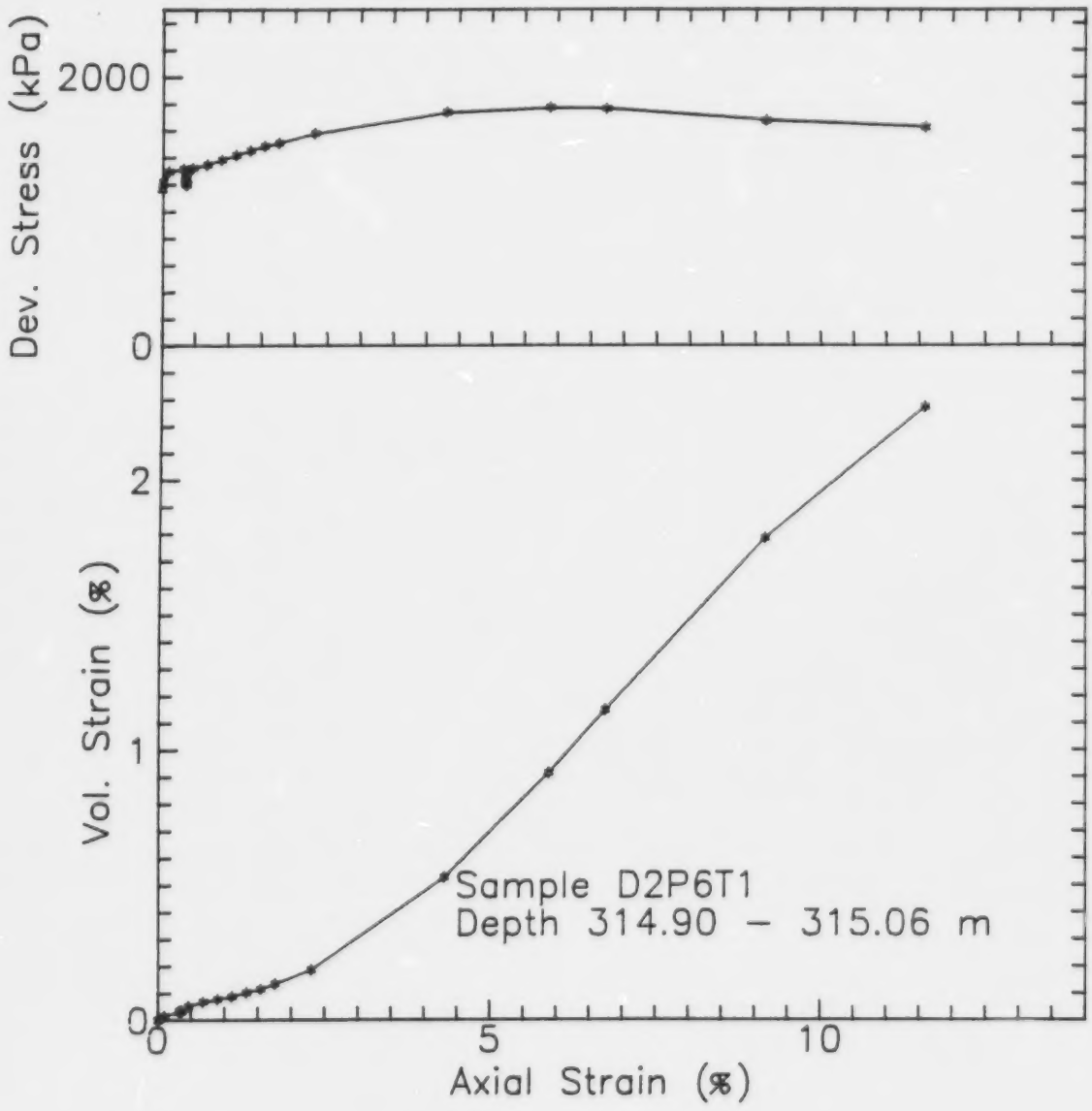
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: B1P4T1

DEPTH: 295.68 - 296.03 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 1

DATE TEST COMPLETED: 11 February 1990

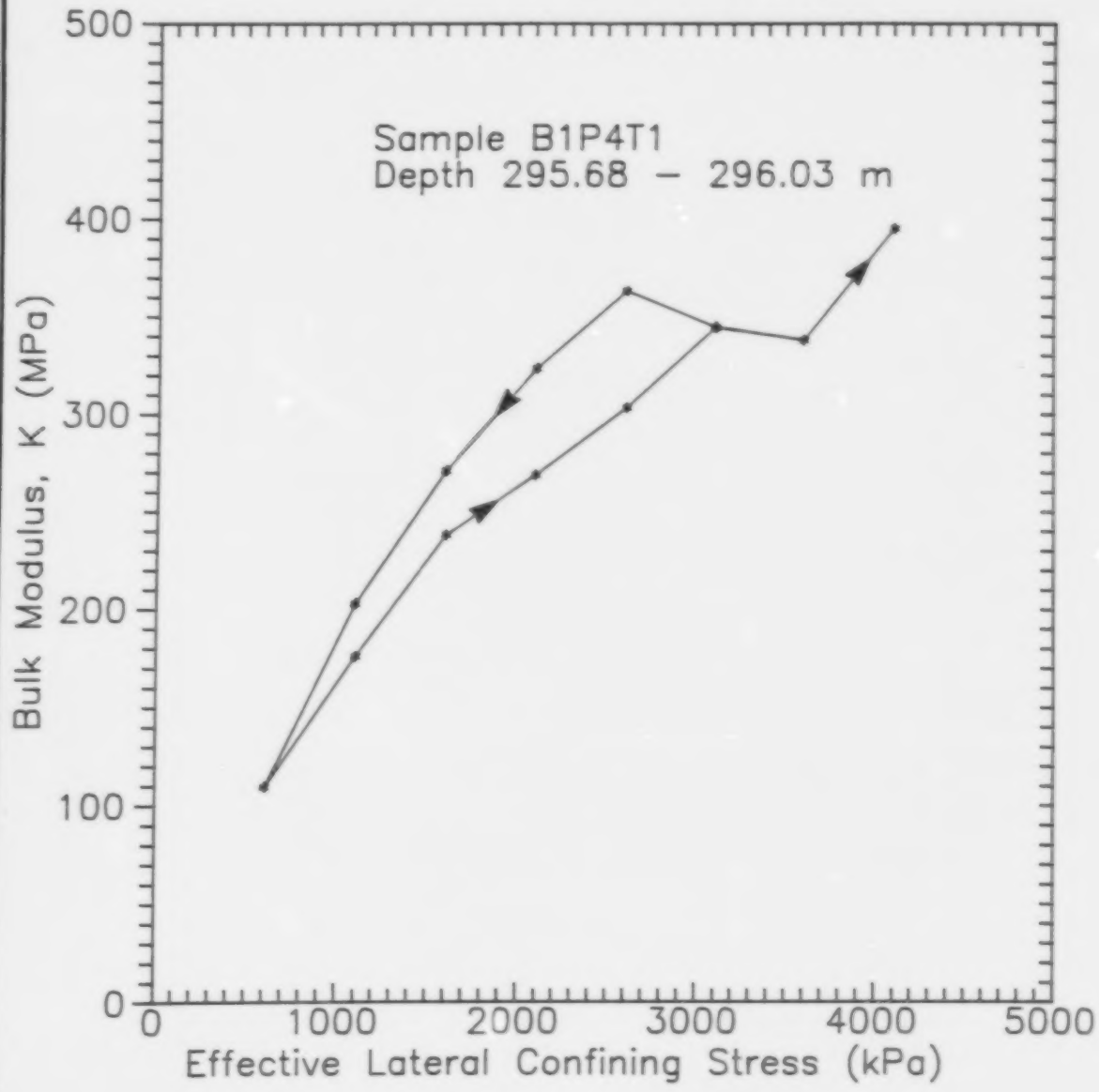
DEVIATIONS FROM STANDARD TEST PROCEDURE: #4 & #5 Horizontal effective stress = 200 kPa

#10 & #13 Back pressure was increased and decreased by 500 kPa in 250 kPa increments

#16 Prior to unloading the sample was strained to 17% axial strain

REMARKS:

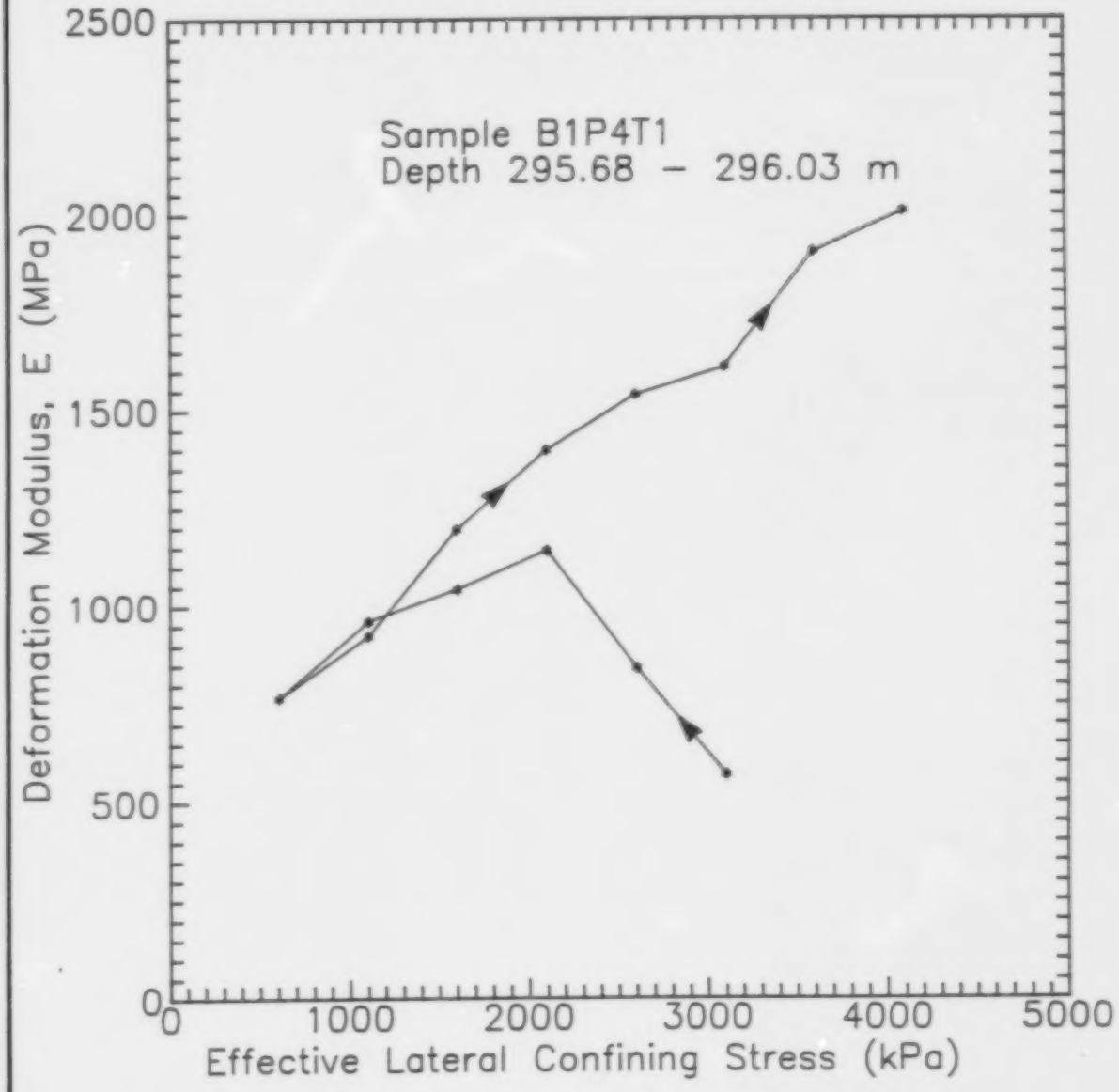
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

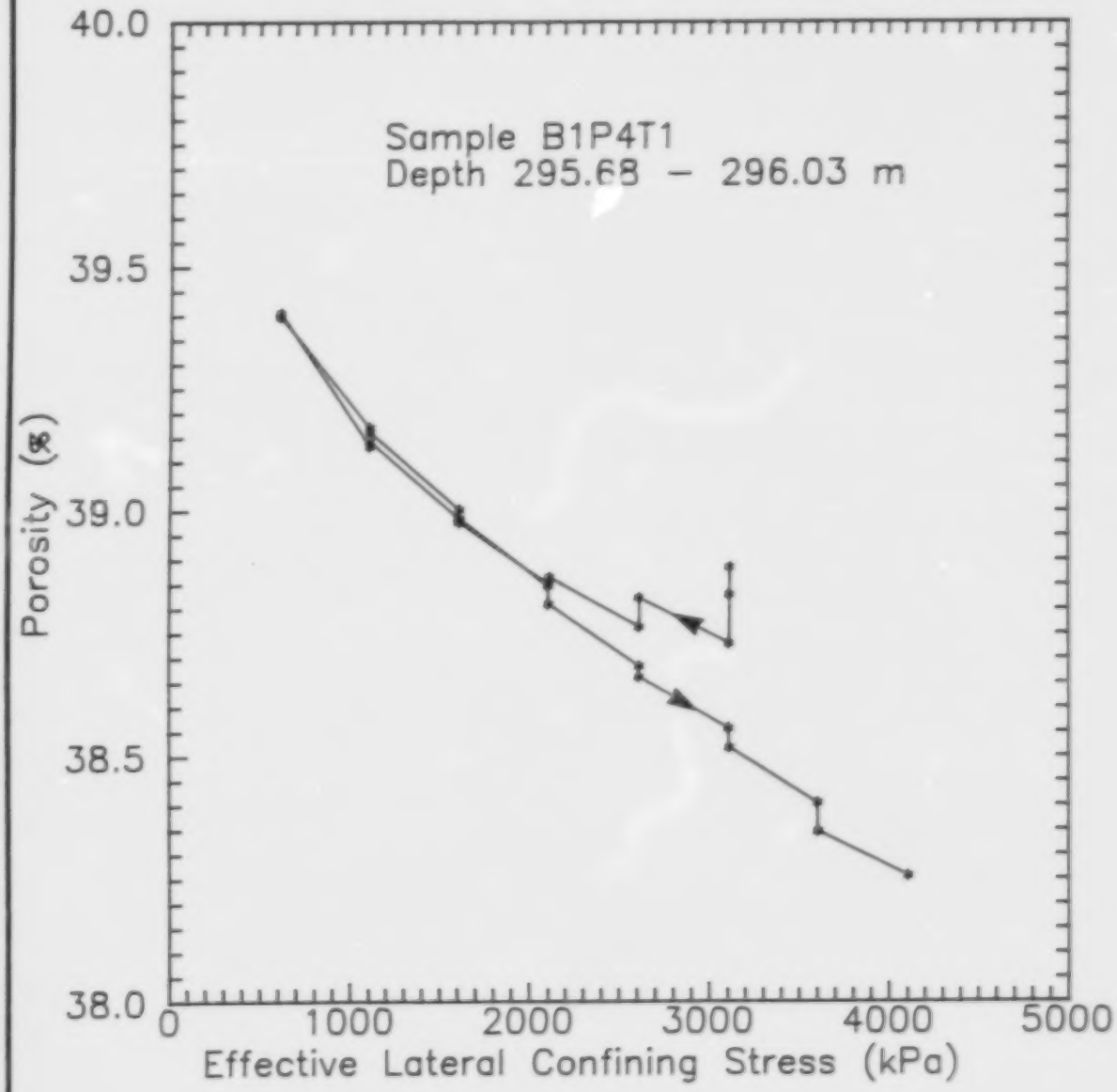
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: B2P3T1

DEPTH: 308.47 - 308.82 m

GEOLOGICAL UNIT: Upper ~~Lower~~ Sand

VISUAL DESCRIPTION: Oil Sand

TYPE OF TEST: Task 1

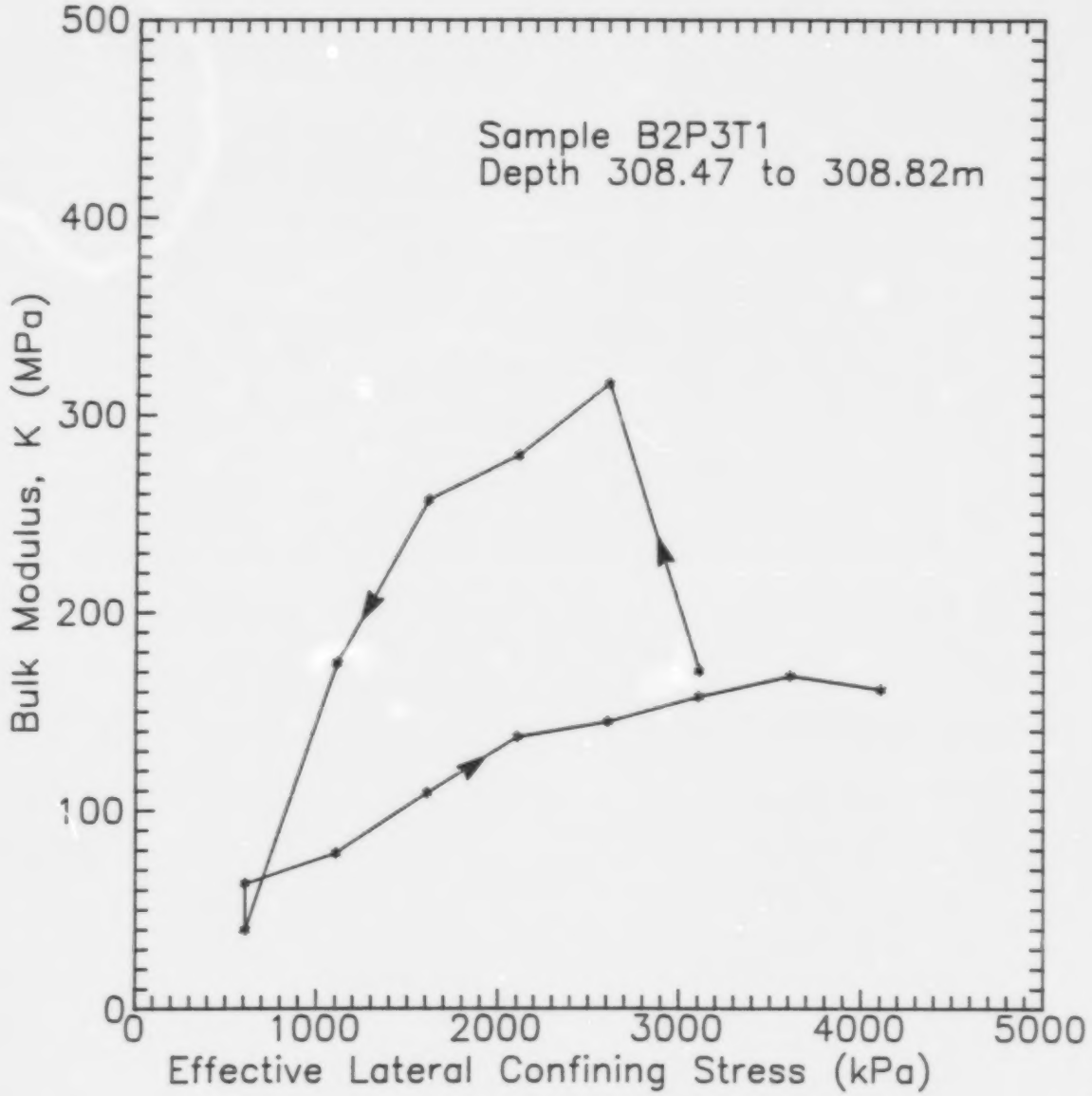
DATE TEST COMPLETED: 14 March 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 & 05 Effective Confining stress = 200 kPa

013 & 015 Back pressure increased and decreased in 500 kPa increments

REMARKS:

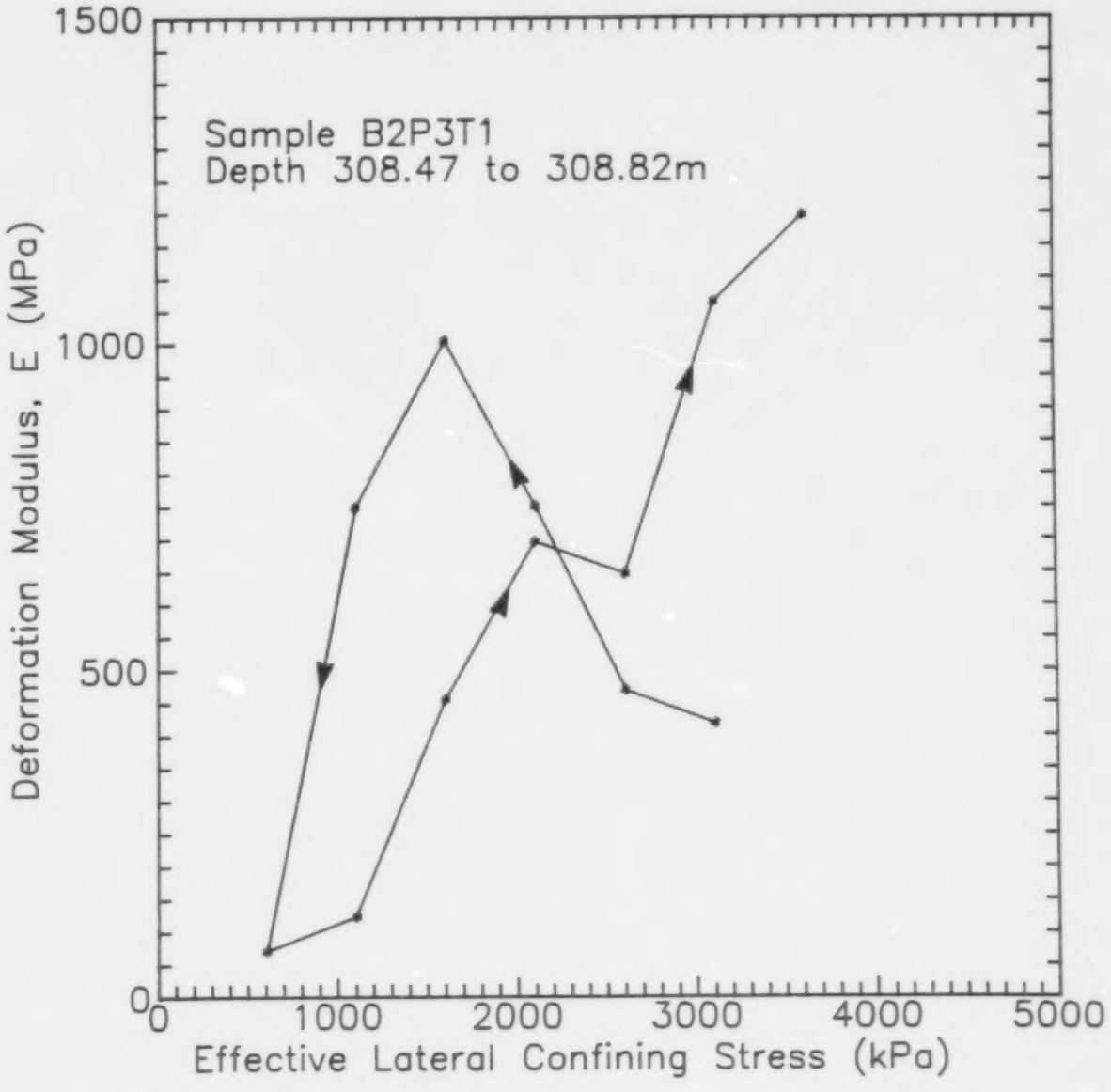
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

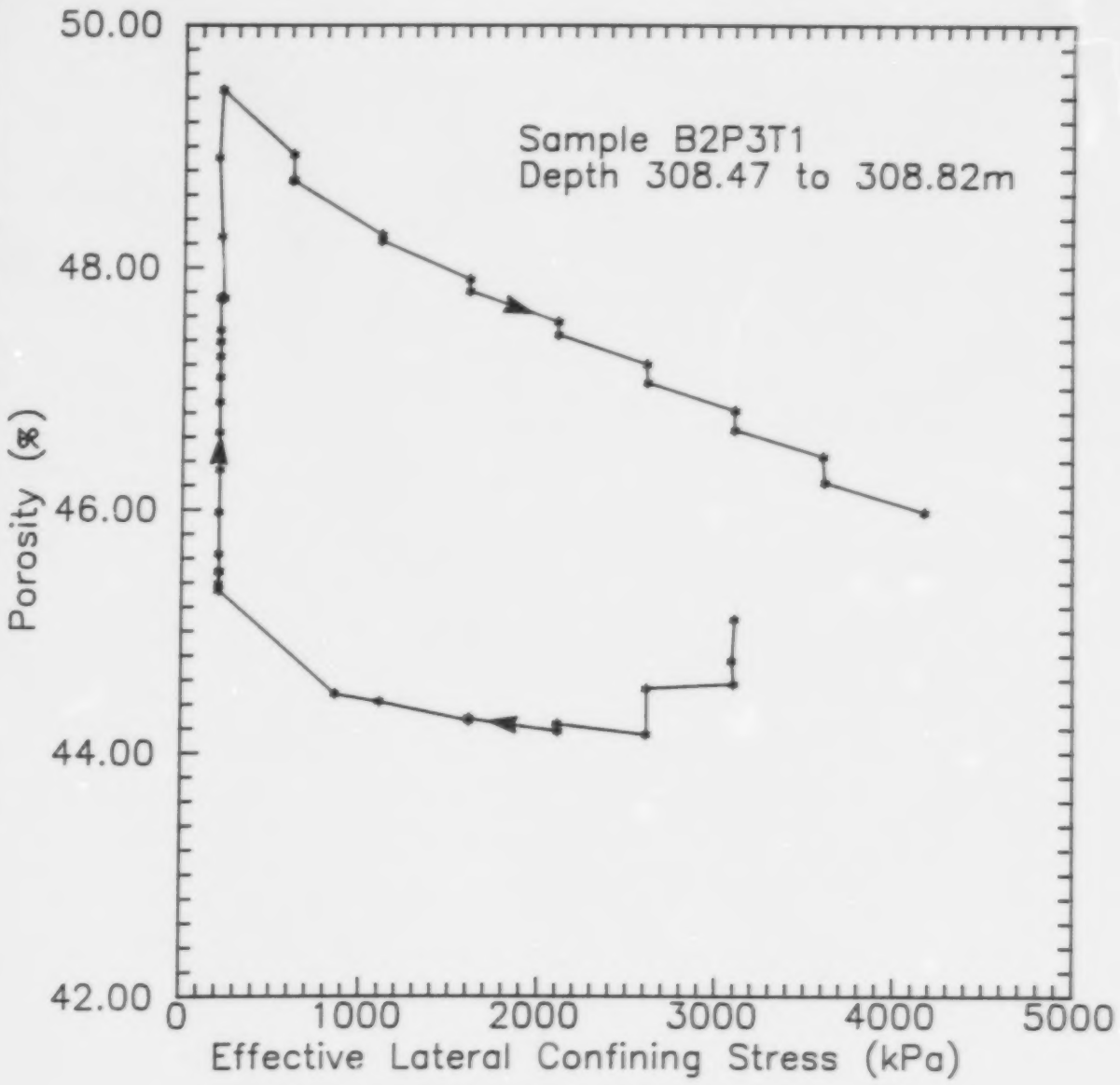
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure

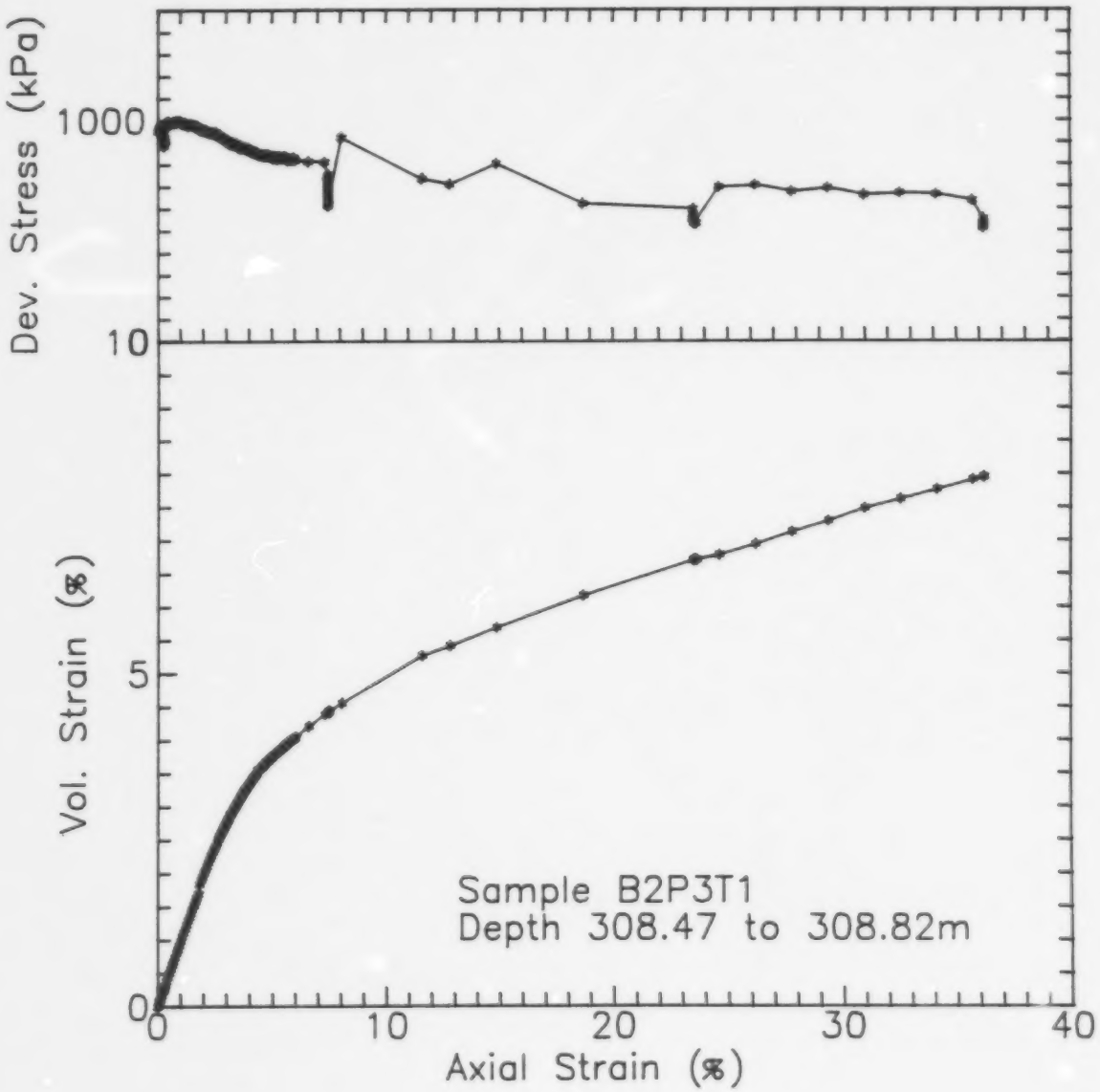


Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: B2PIT1

DEPTH: 296.86 - 297.22 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 1

DATE TEST COMPLETED: 19 March 1990

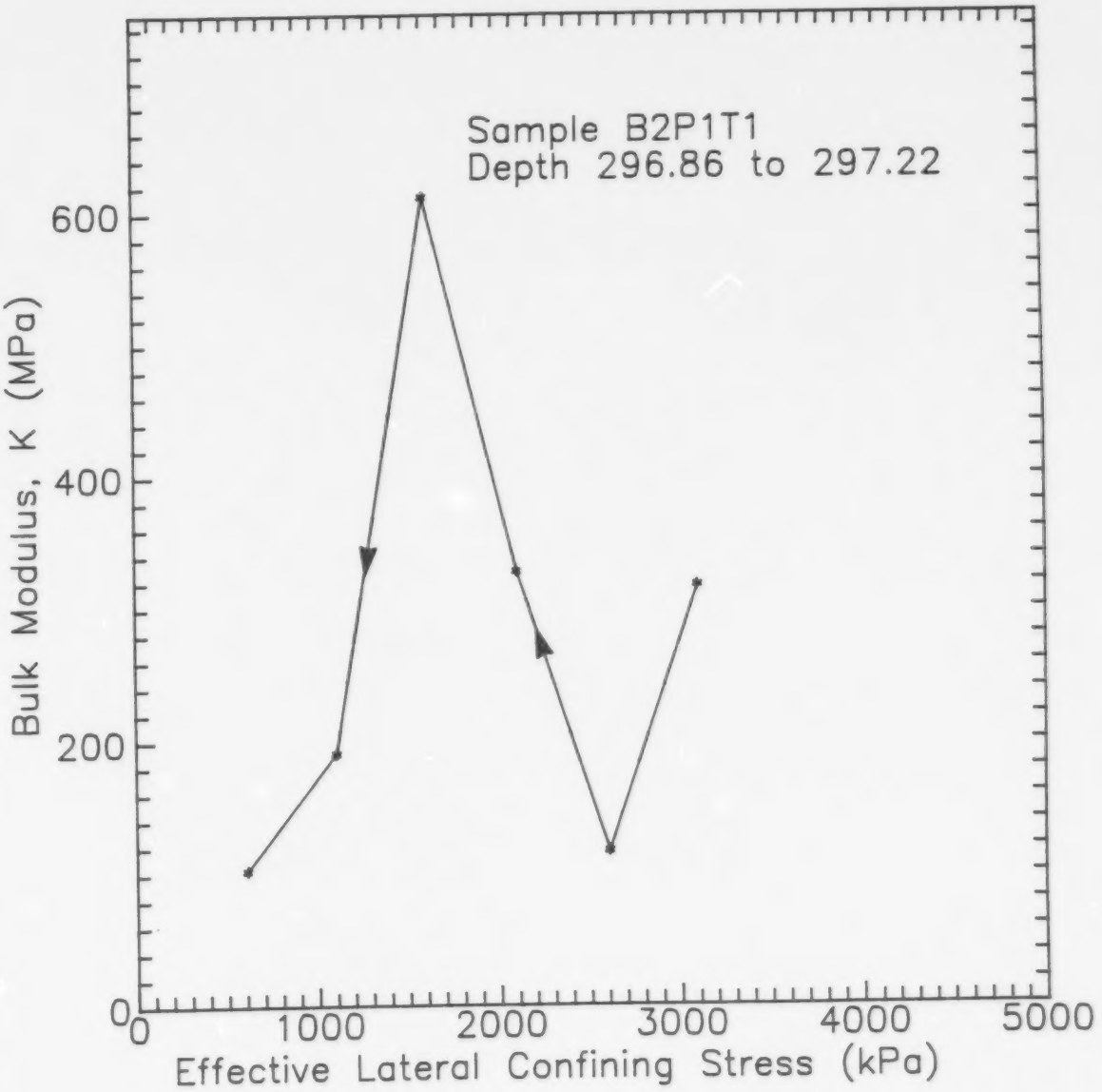
DEVIATIONS FROM STANDARD TEST PROCEDURE: B4 & B5 Effective Confining stress = 200 kPa

B13 Back pressure increased and decreased in 500 kPa increments

B15 Test was ended after failure

REMARKS:

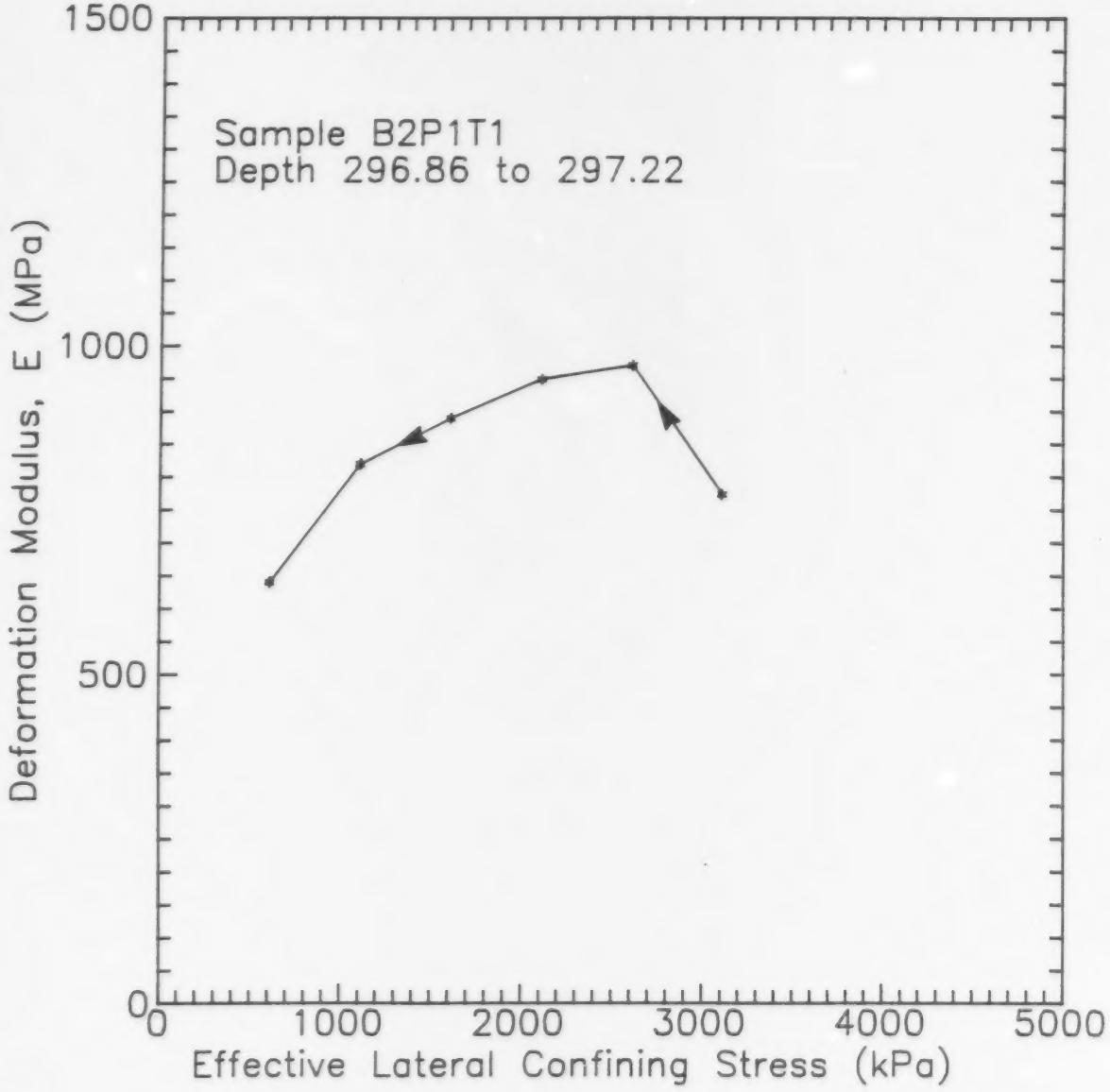
Figure



Task 1 – Proportional Unloading and Reloading

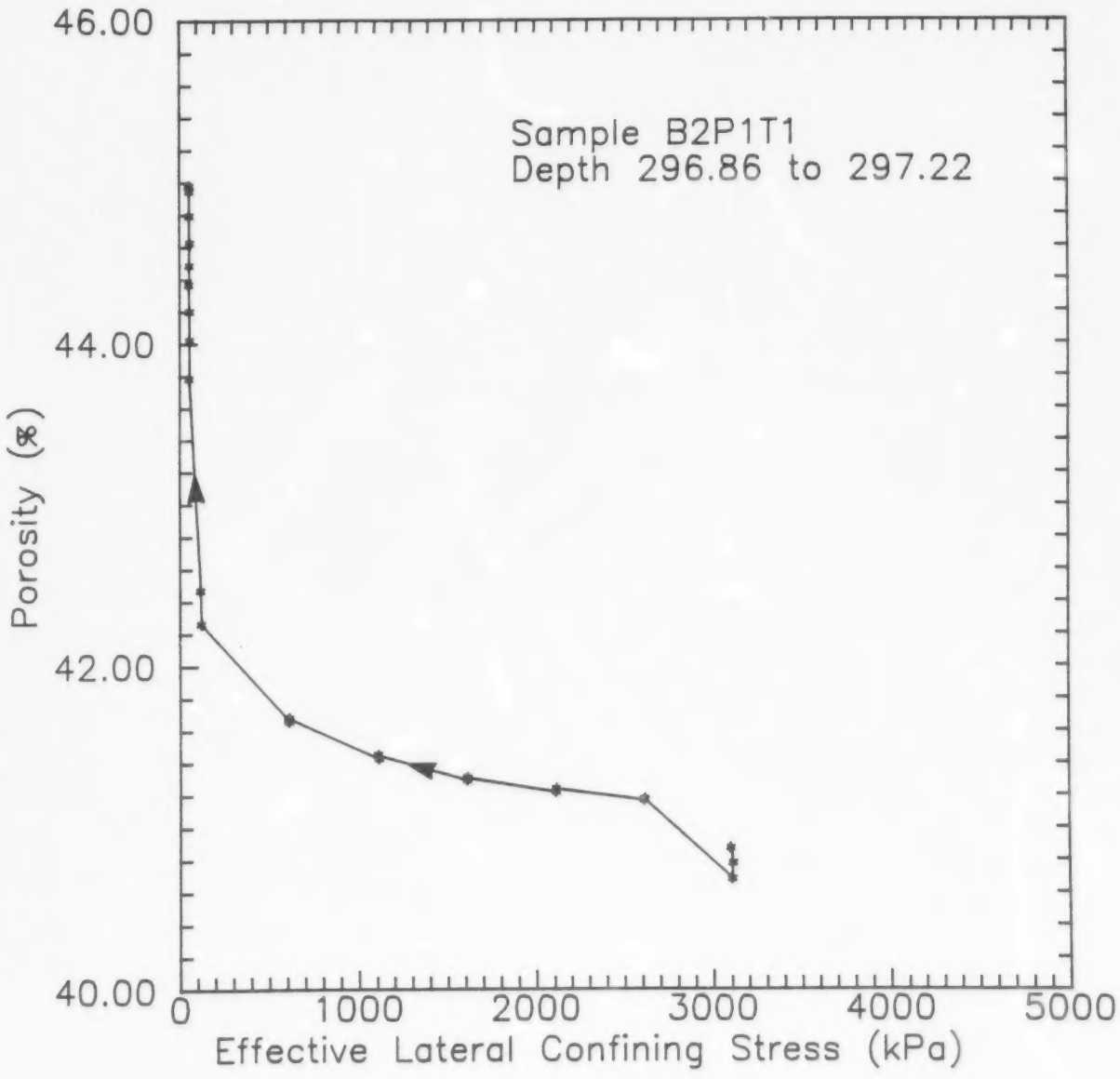
PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

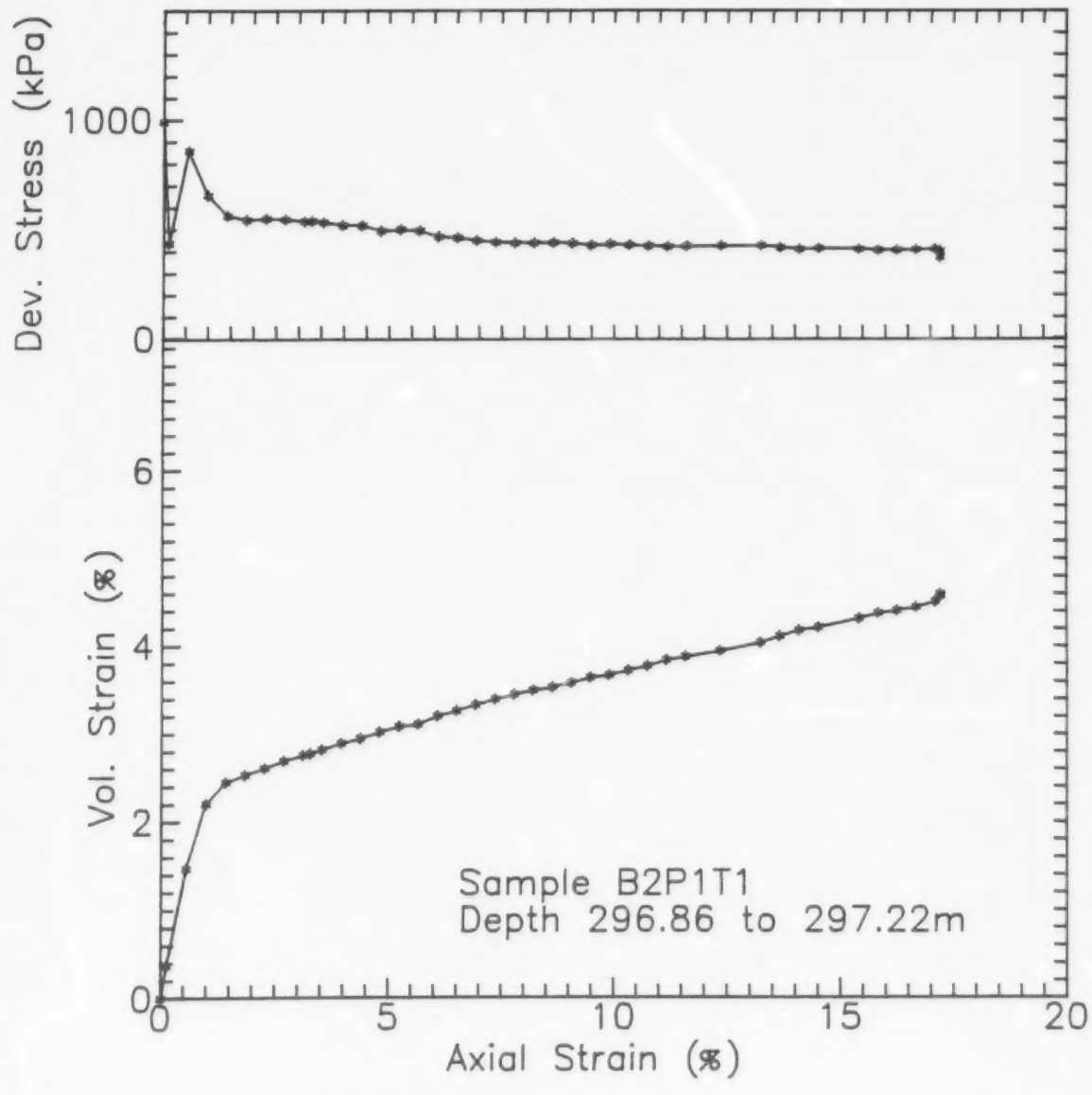
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C1P2

DEPTH: 290.81 - 291.16

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand, much sample disturbance

TYPE OF TEST: Task 1

DATE TEST COMPLETED: 23 May 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #4 and #5 Effective confining stress = 200 kPa

#5 Pore pressure increased to 4 MPa, then B test was carried out

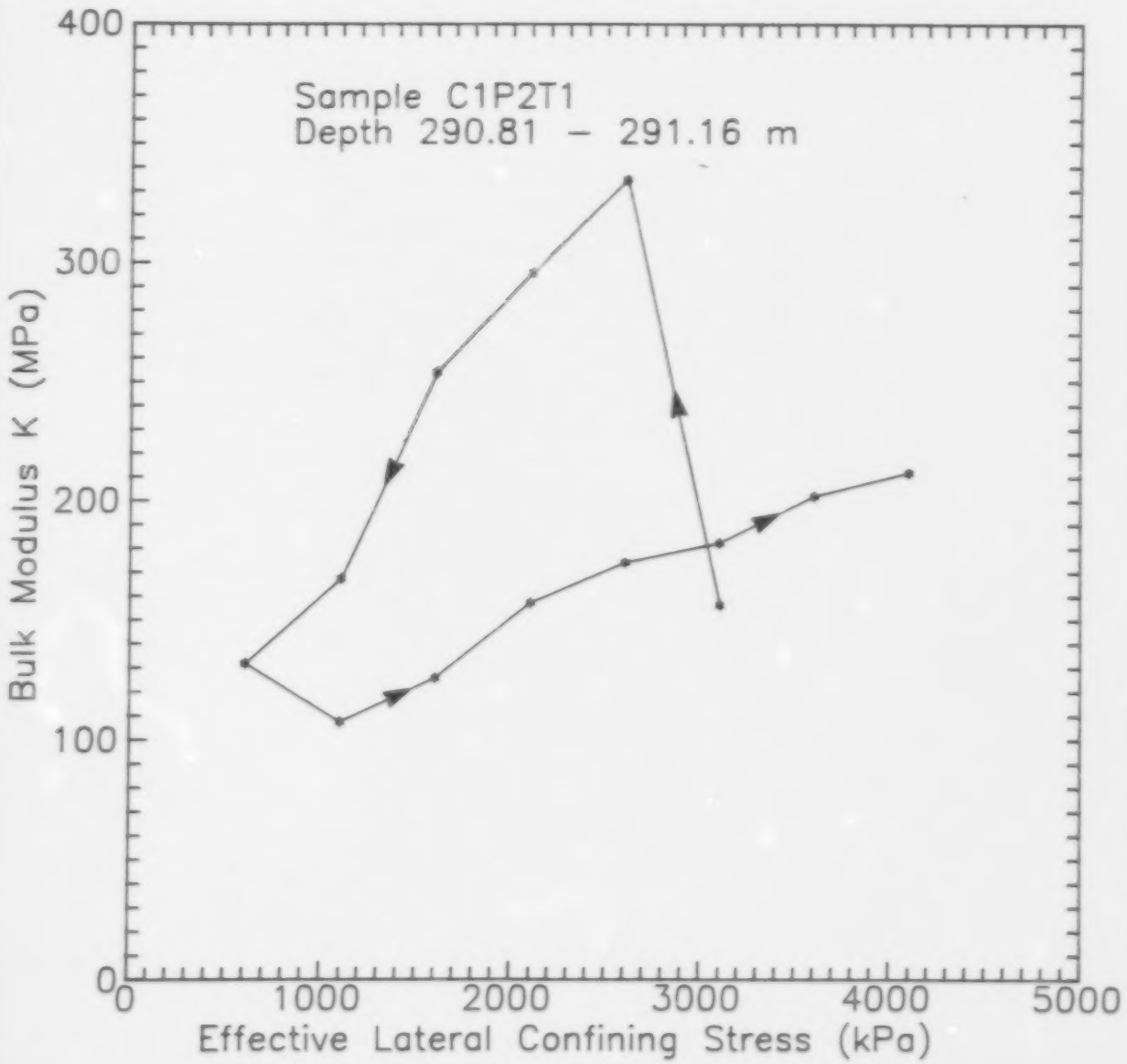
#10 Pore pressure was increased by 500 kPa

#12 Sample was strained 12% at failure envelope

#13 Pore pressure was inceased by 500 kpa

REMARKS:

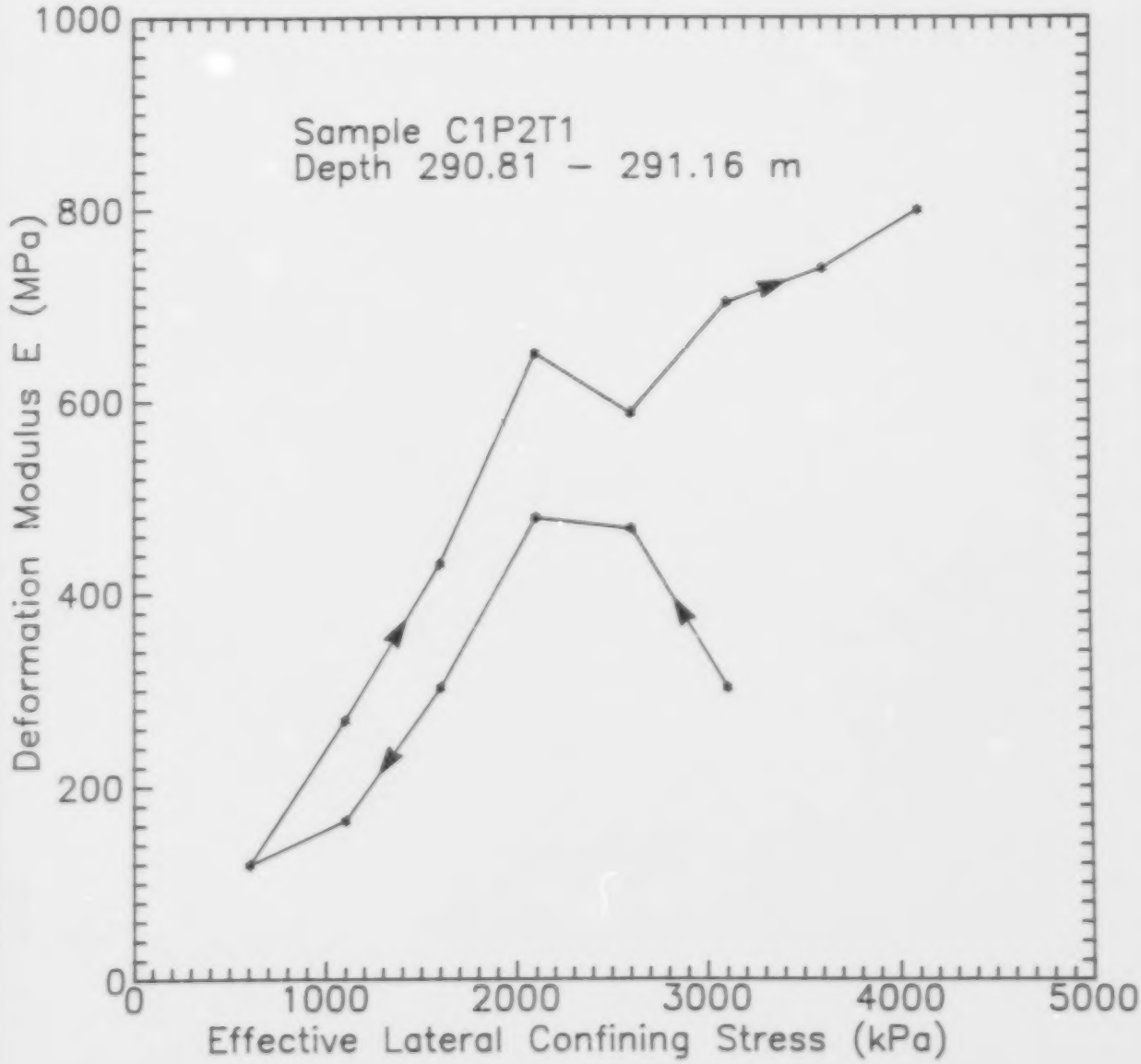
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

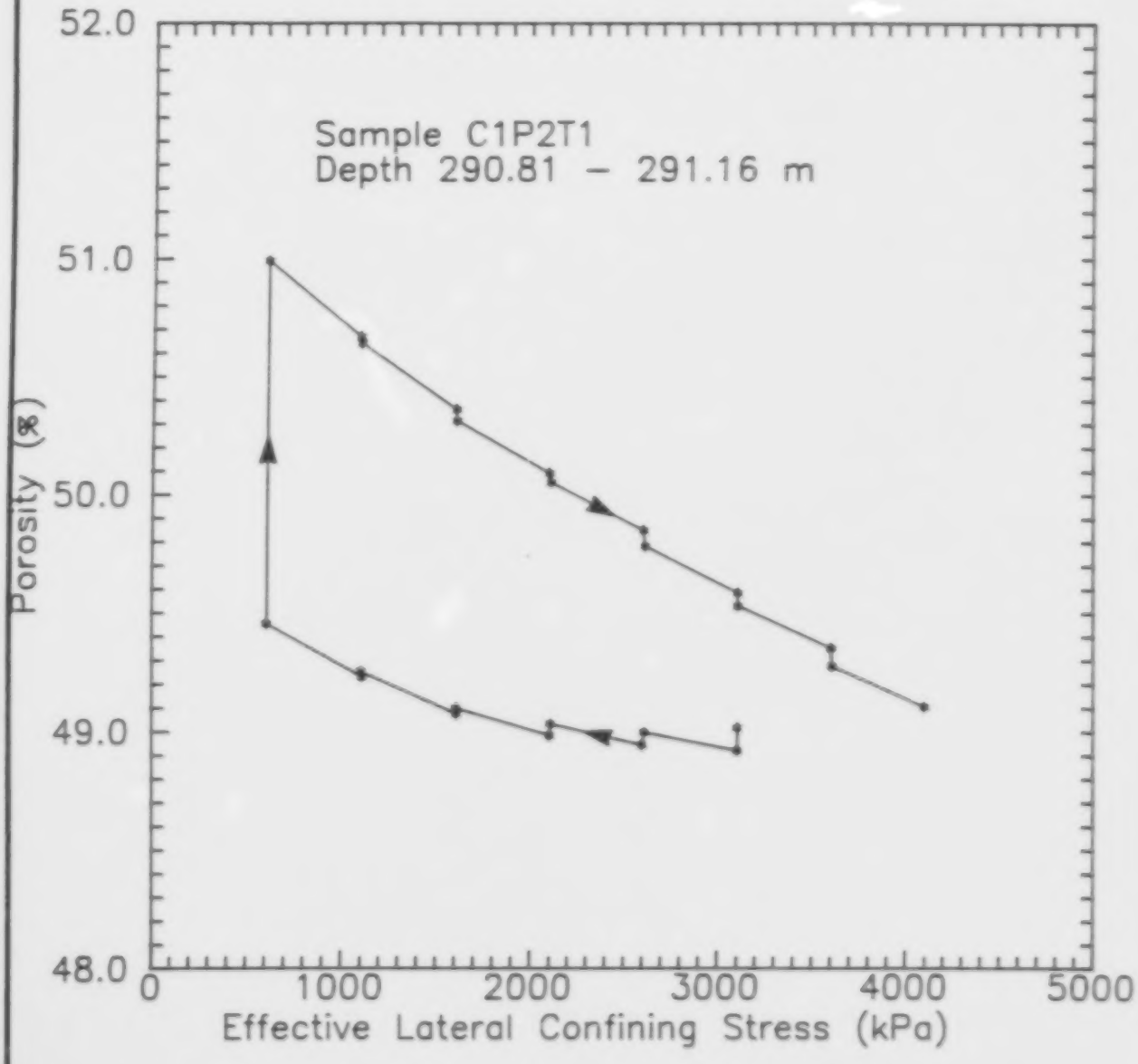
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure

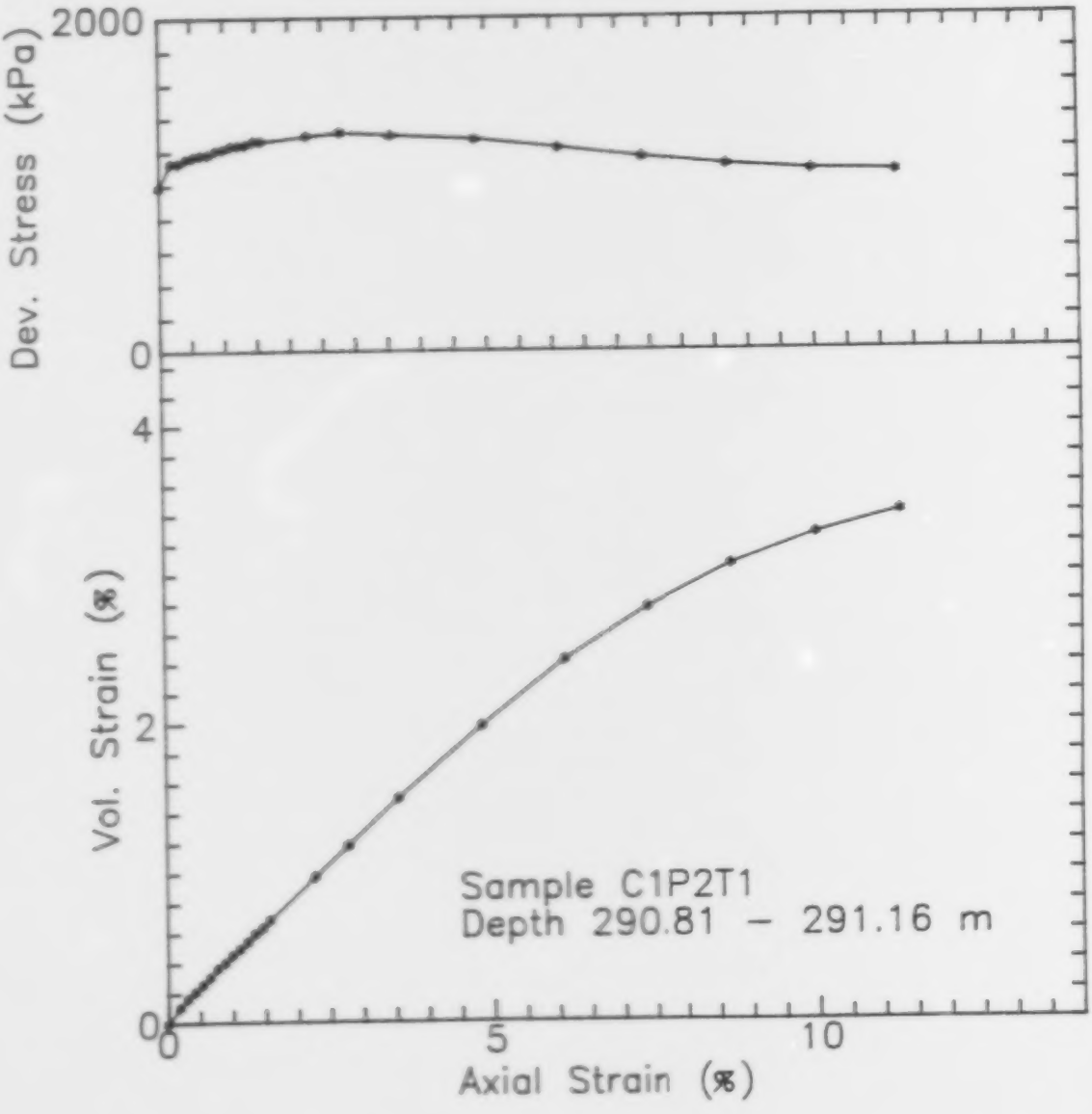


Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C3P2T1

DEPTH: 328.20 - 328.61 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 1 (Modified Procedure)

DATE TEST COMPLETED: 31 May 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stres = 200 kPa

05 Pore pressure increased to 4 MPa, then B test was carried out

010 Pore pressure was increased by 500 kPa

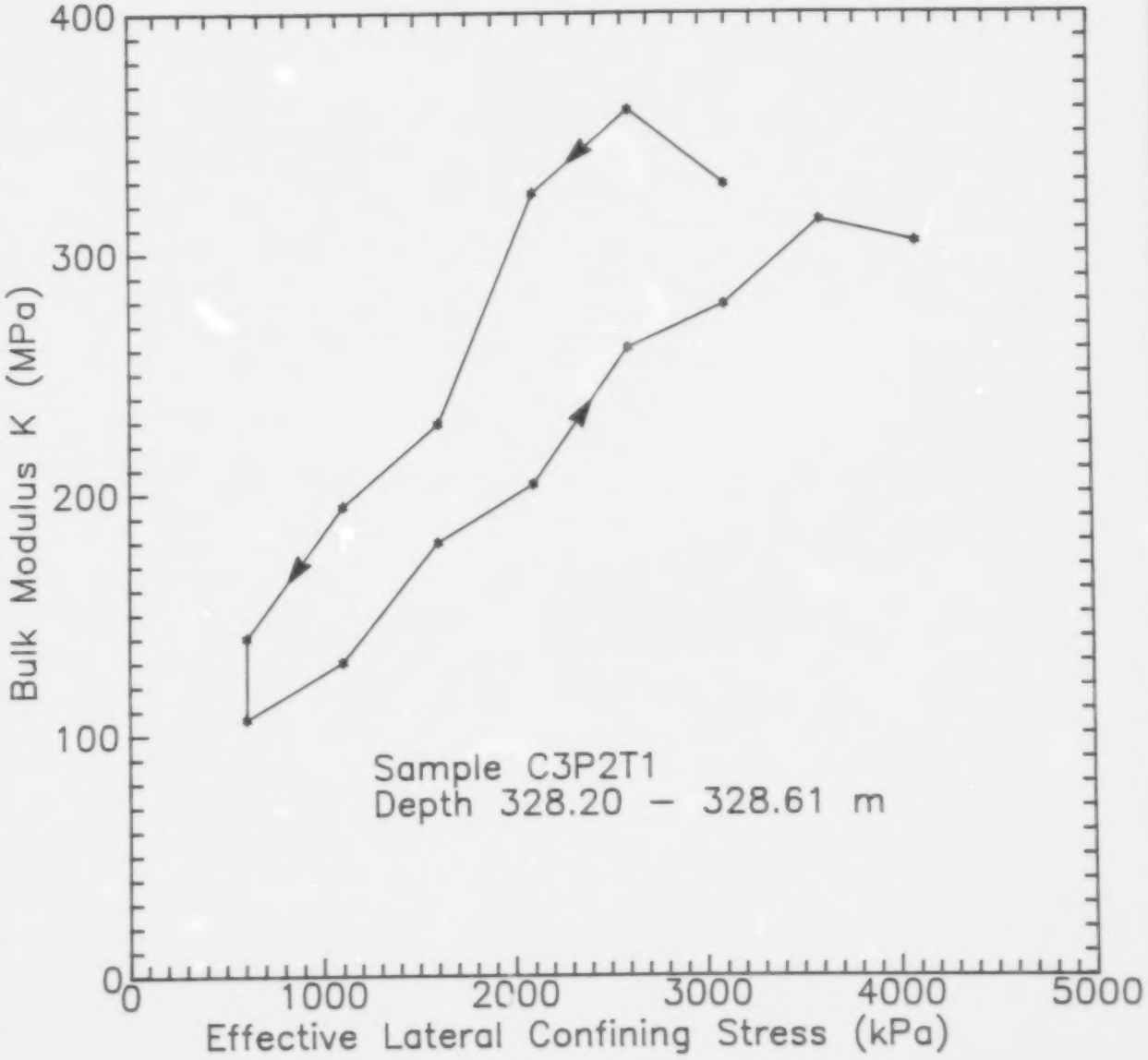
012 Saaple was strained 12% at failure envelope

013 Pore pressure was decreased by 500 kPa

failure envelope

REMARKS:

Figure

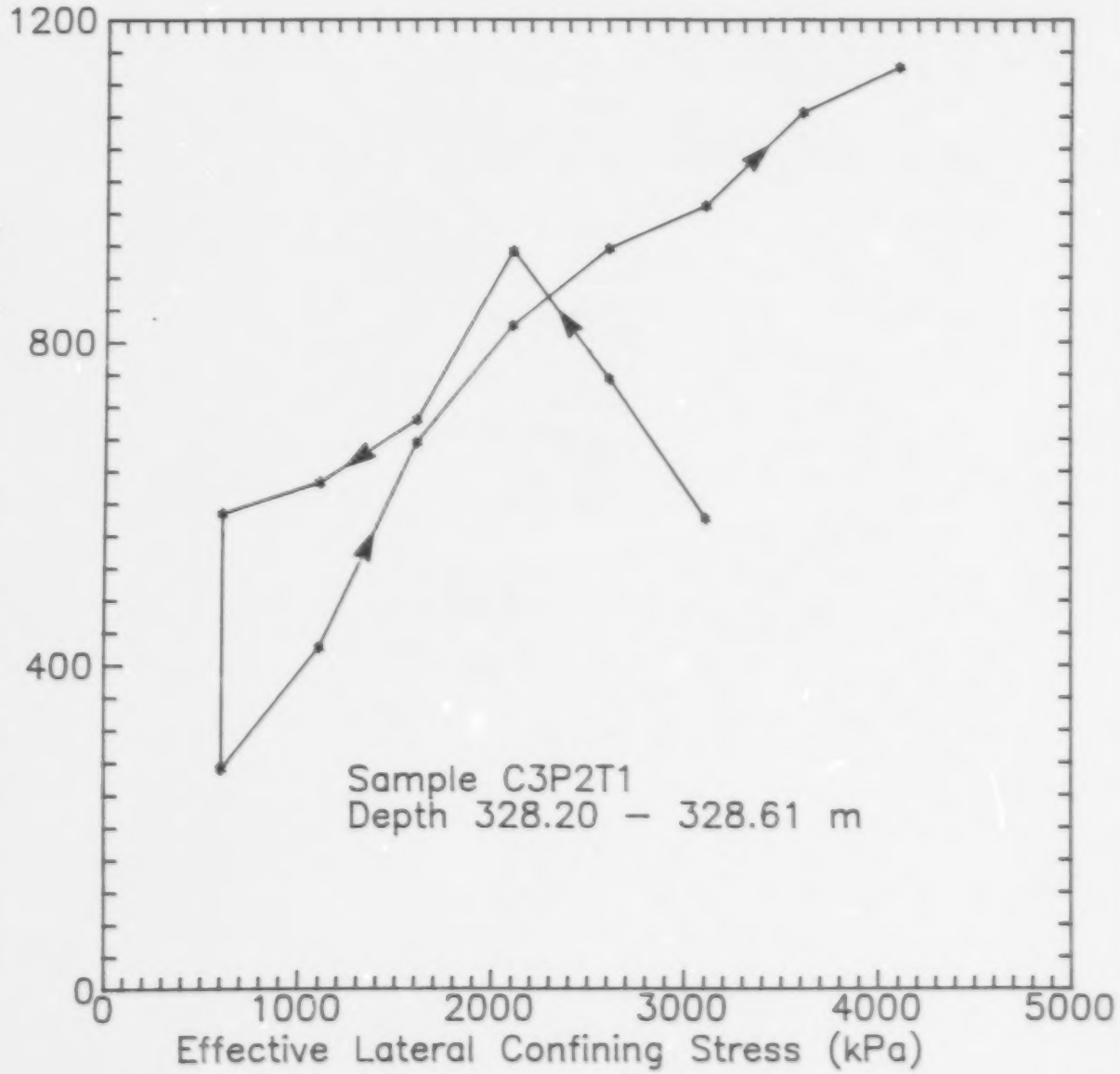


Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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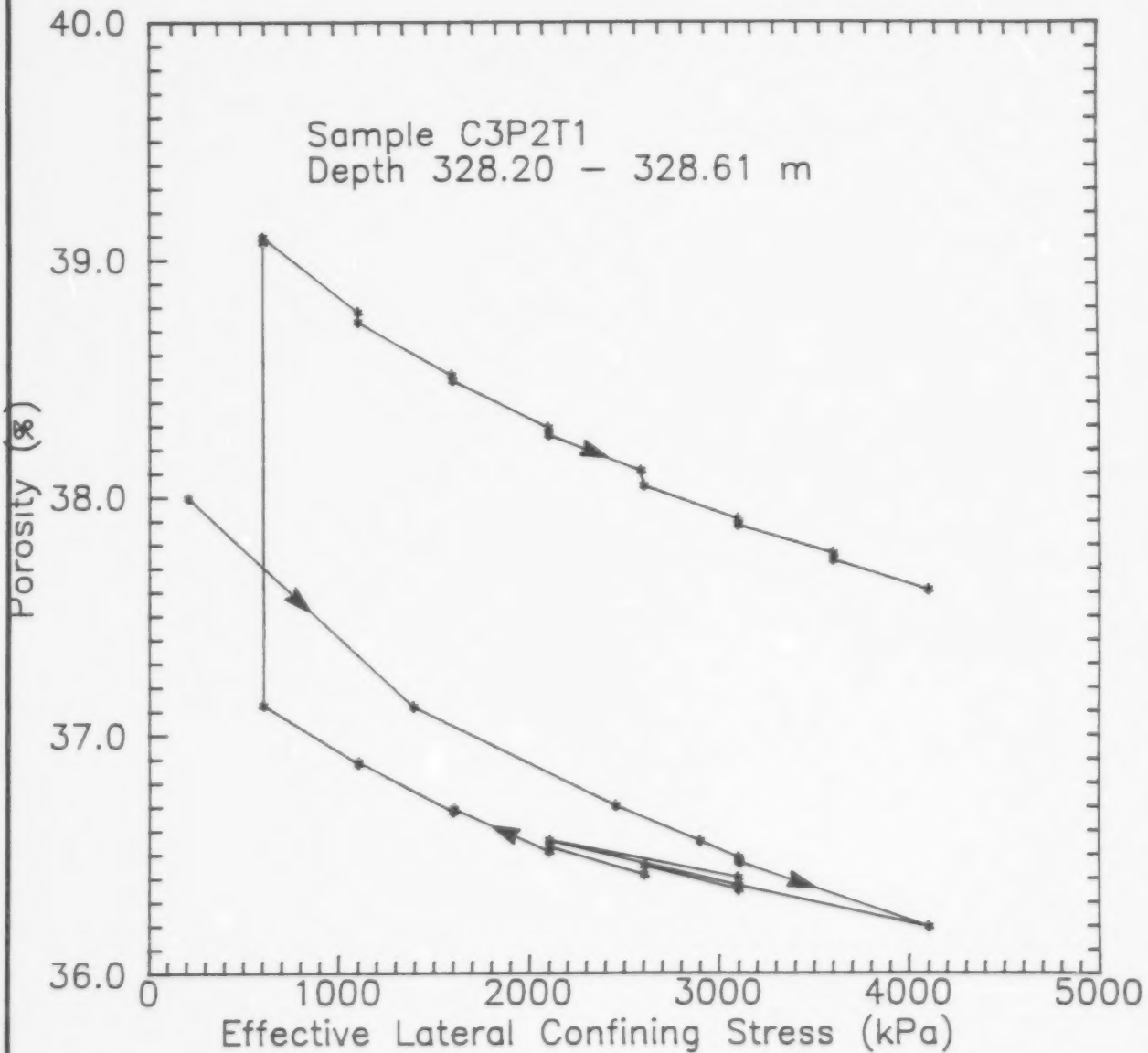
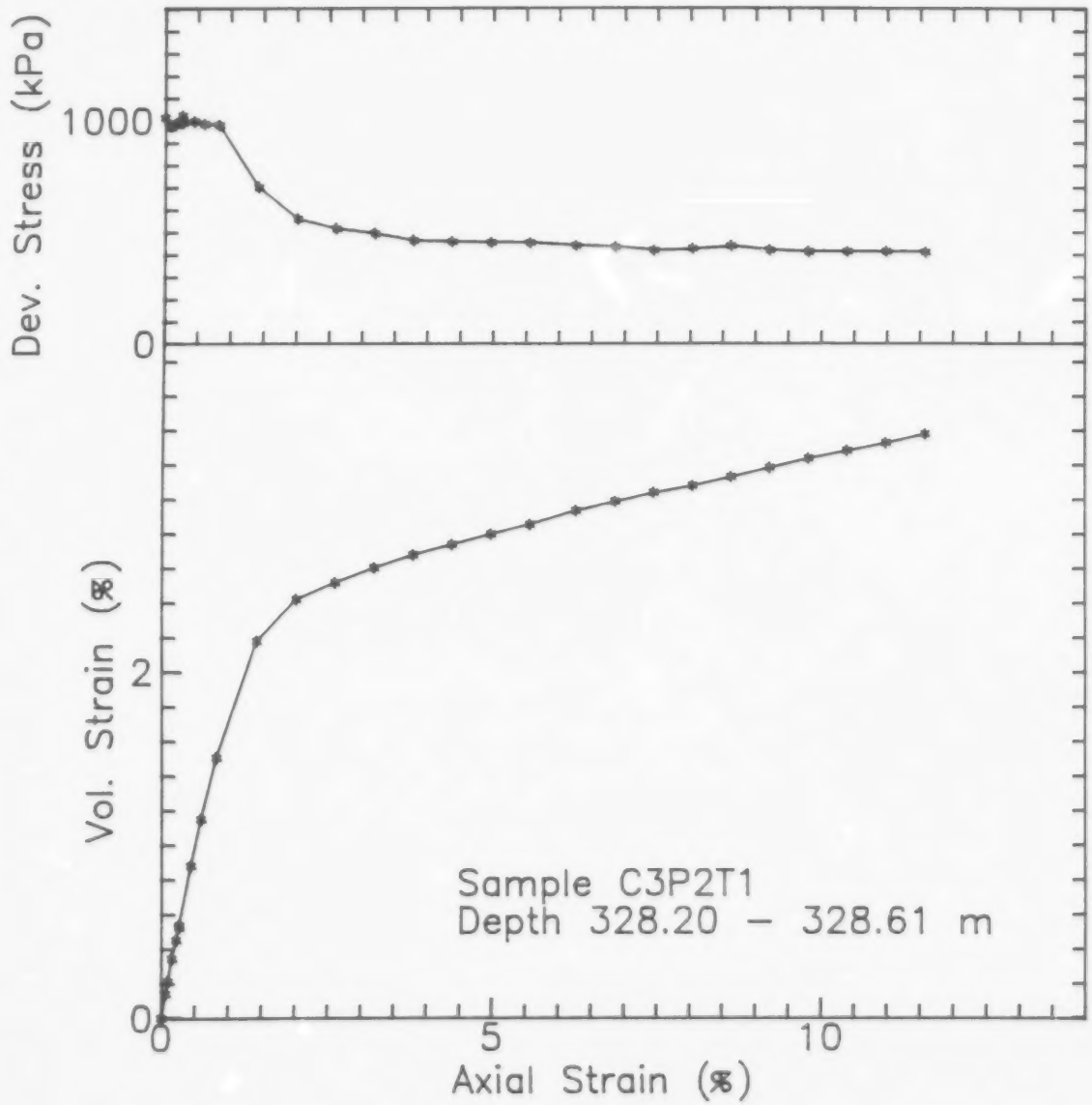
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C3P3T1

DEPTH: 328.99 - 329.37

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Extensive cracking, poor sample, no shale bands

TYPE OF TEST: Task 1 with 3 cycles

DATE TEST COMPLETED: 23 July 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #4 and #5 Effective confining stress = 200 kPa

#5 Pore pressure increased to 4 MPa, then B test was carried out

#10 Pore pressure was increased by 500 kPa

#12 Sample was strained 6% or less at failure envelope

#13 Pore pressure was decreased by 500 kPa

#16 Repeat steps 10 to 15 two more times for a total of 3 cycles

#15 For 1st two cycles reload to insitu stress, on 3rd cycle

continue decreasing u to 1 Mpa above the insitu stresses

REMARKS: oil 12.7% water 2.0% solid 85.3% (by mass)

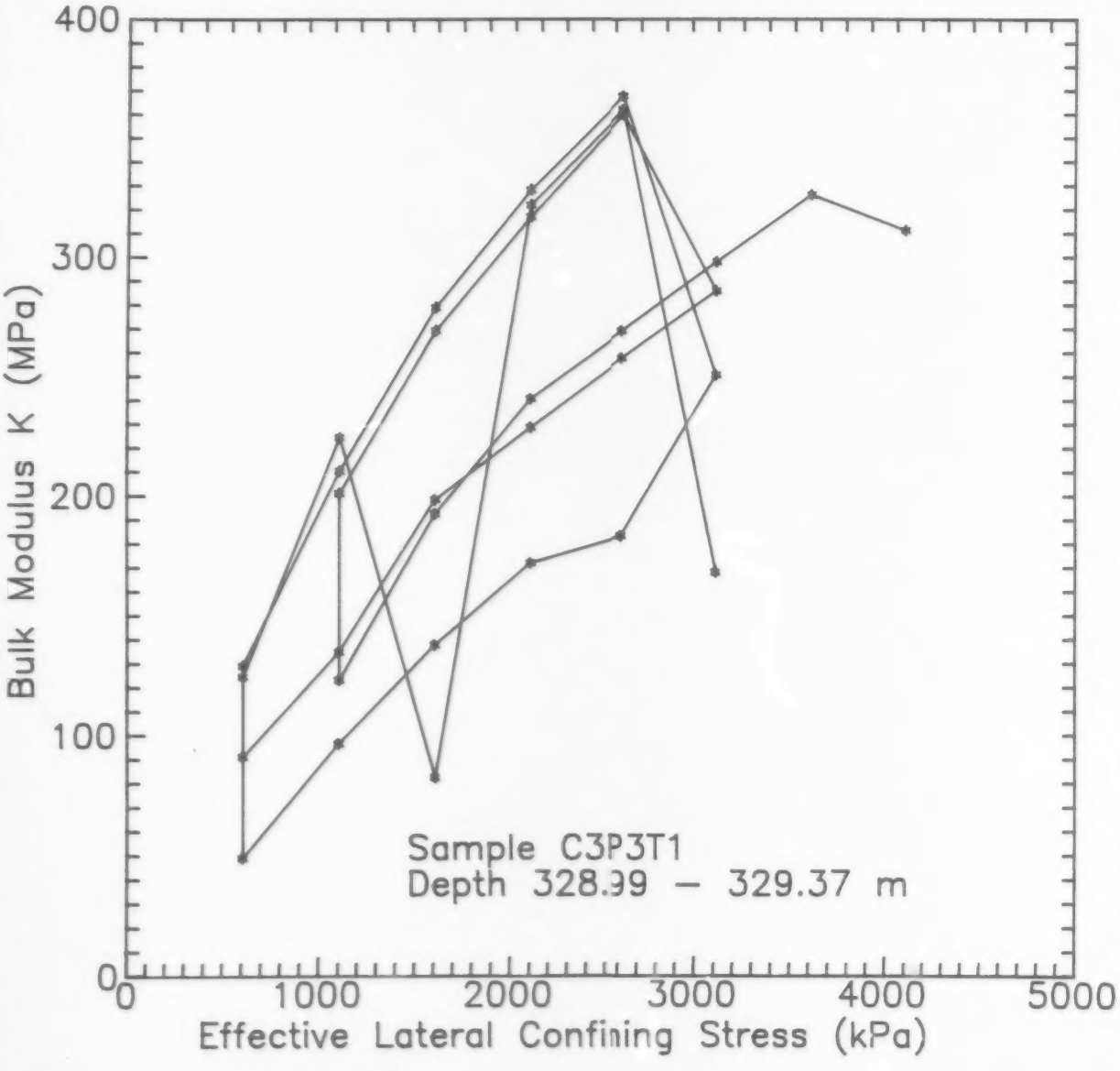
porosity before testing 43.2%

porosity in situ 31.3%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 38.1%

Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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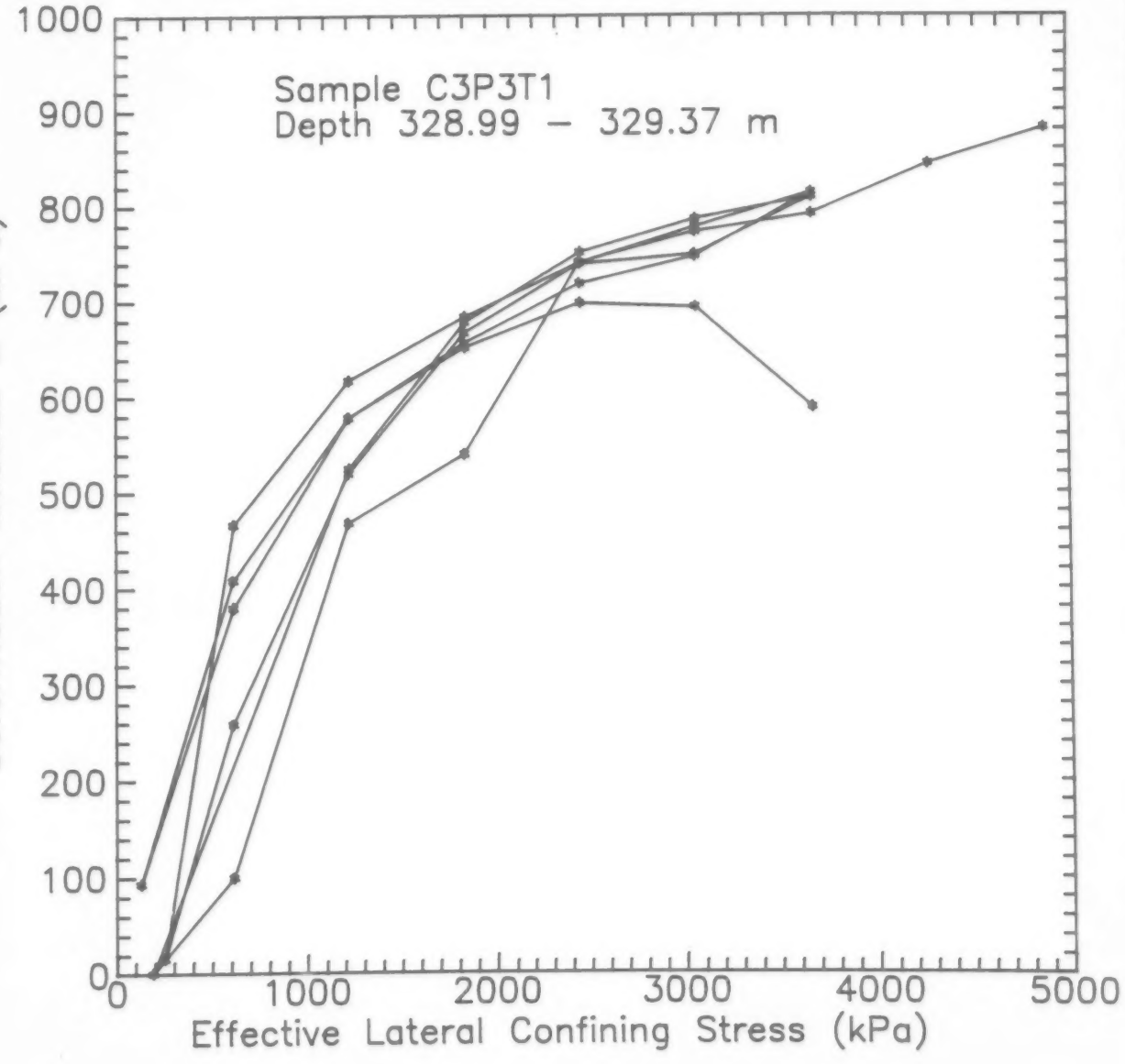
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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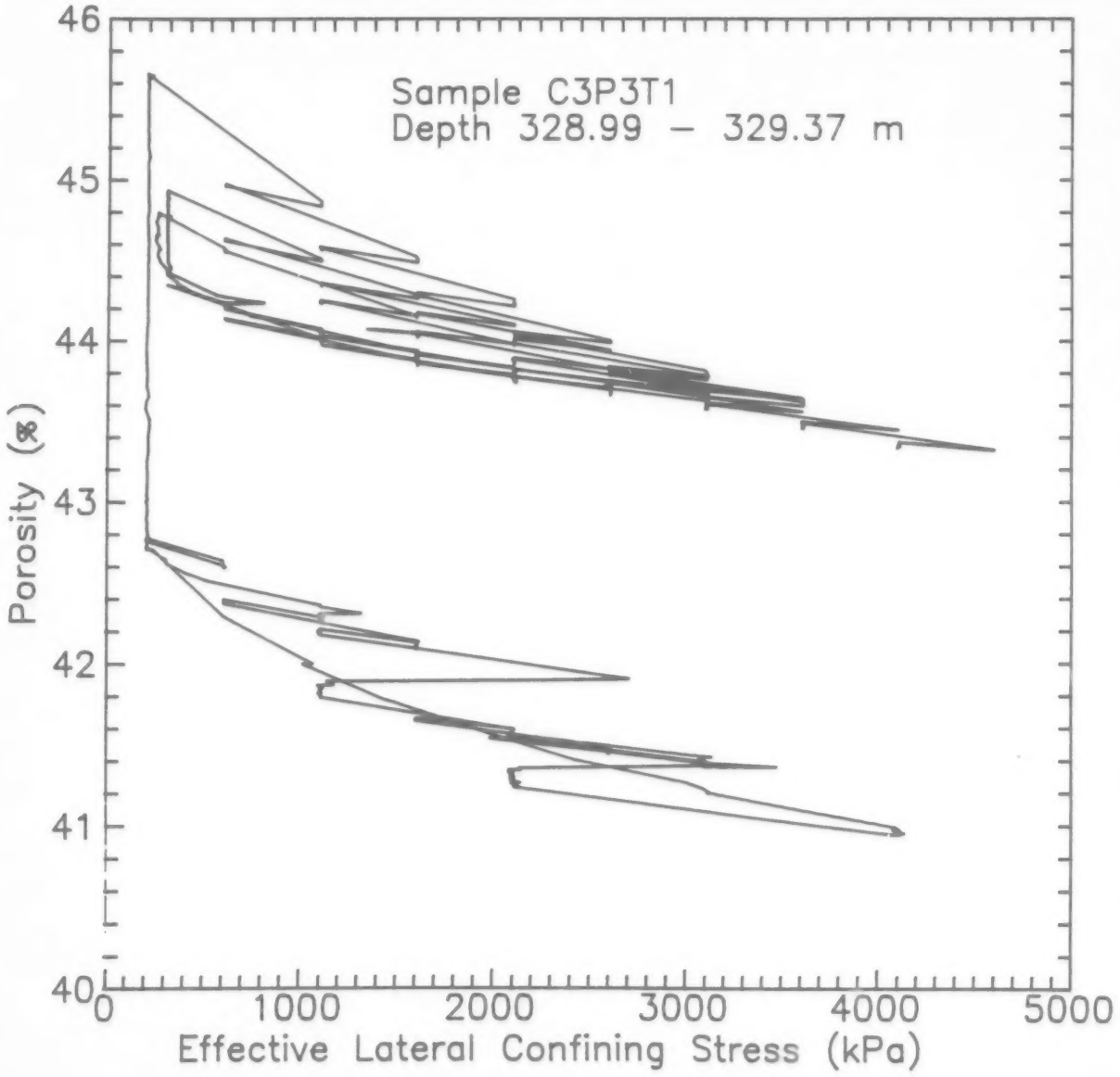
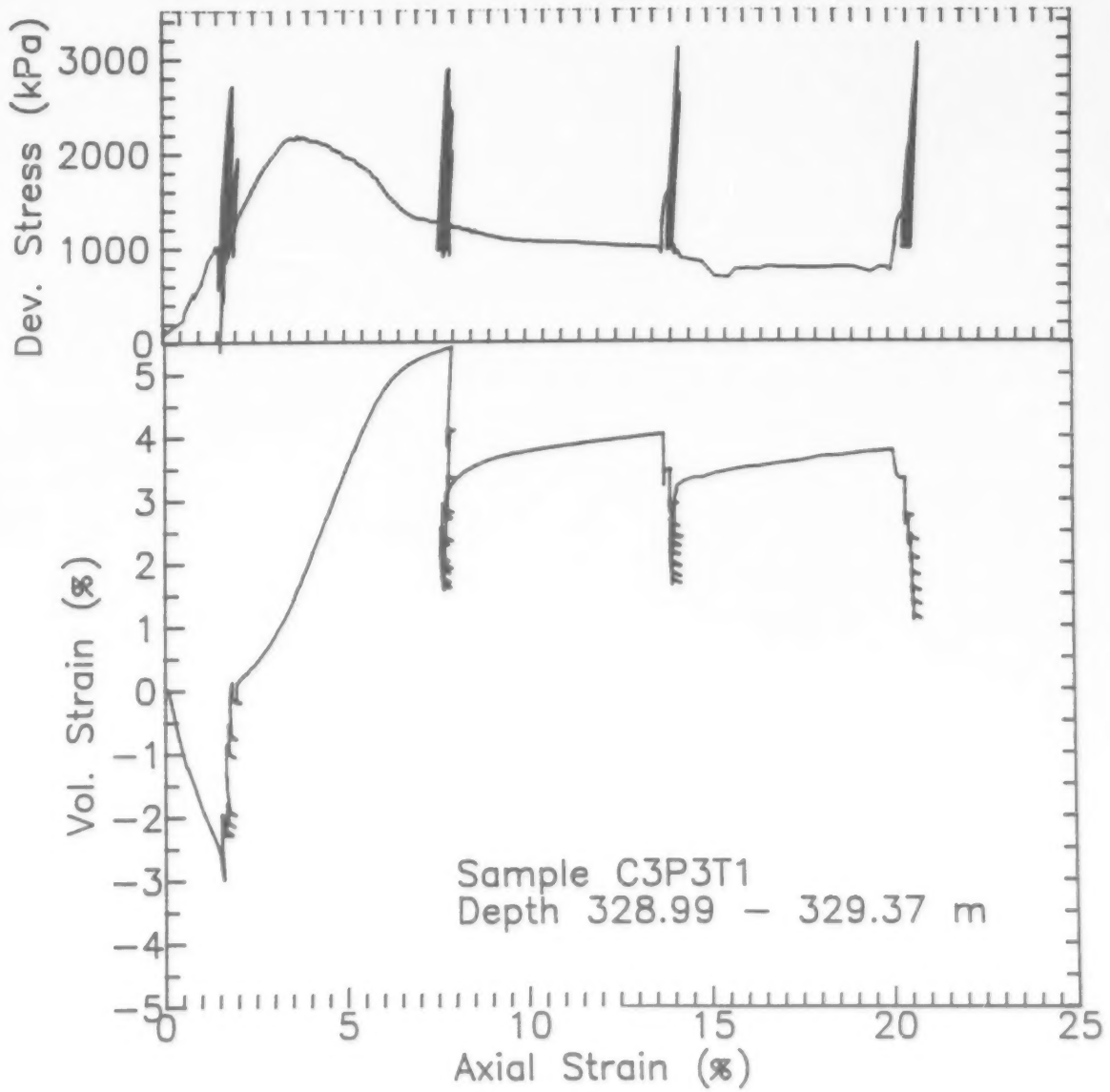
Figure



Task 1 – Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure X



Task 1 − Proportional Unloading and Reloading

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

APPENDIX III - TASK 2 TEST RESULTS

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CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: B2P7T2

DEPTH: 329.20 - 329.55 m

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Band

TYPE OF TEST: Test 2

DATE TEST COMPLETED: 04 March 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: B5 Sample was flushed with Toluene followed by water. The sample was then placed under vacuum and refrozen. After refreezing sample, it was placed in triaxial cell for thawing under an effective confining stress of 200 kPa. B12 & B15 Back pressure was increased and decreased by 500 kPa in 250 Kpa increments.

REMARKS: oil 16.4% water 2.8% solid 80.8%

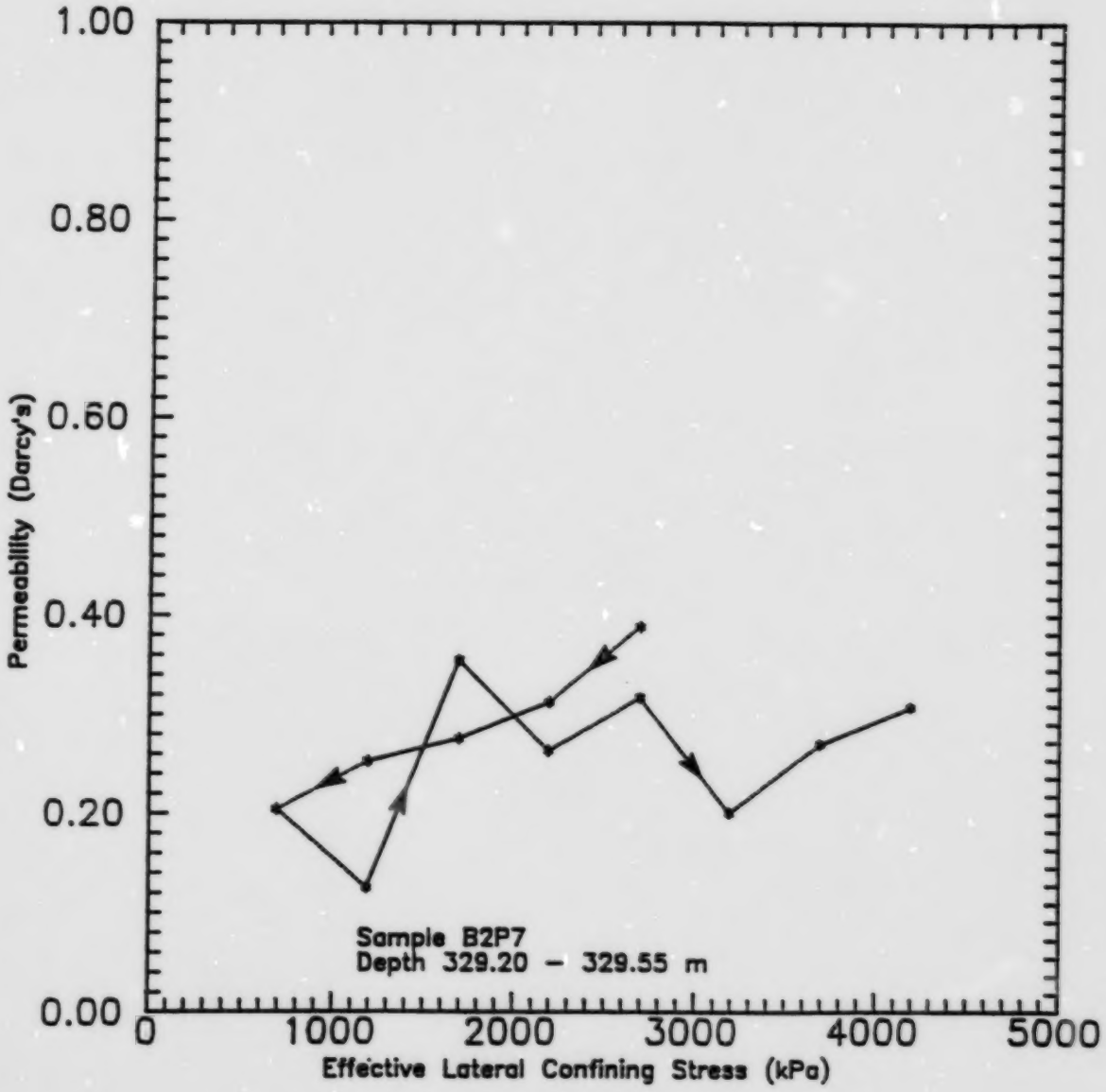
sample density before extraction 1.80 g/cm3

sample density after extraction 1.94 g/cm3

in situ sample porosity 38.6%

Id = 18.1%

Figure



Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C1P4T2

DEPTH: 313.45 - 313.80 m

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Sand

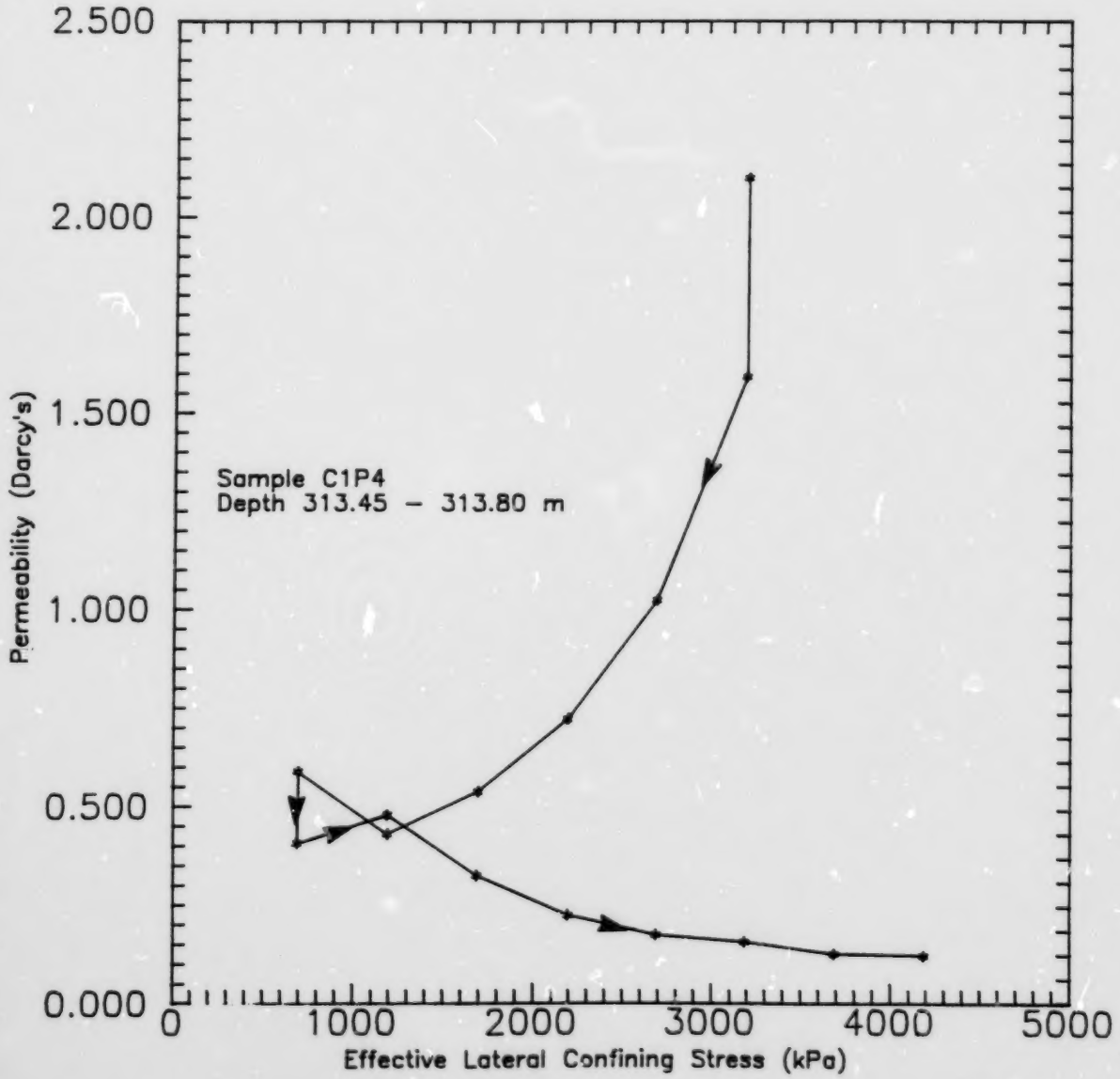
TYPE OF TEST: Task 2

DATE TEST COMPLETED: 8 May 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 05 Sample was flushed with toluene followed by water. The sample was then placed under vacuum and refrozen. After refreezing sample, it was placed in triaxial cell for thawing under an effective confining stress of 200 kPa.
012 & 015 Back pressure was increased and decreased in 500 kPa increments.
014 Sample was strained 12% at failure.

REMARKS: oil 16.1% water 4.0% solid 79.9%
sample density before extraction 1.73 g/cm3
in situ sample porosity 39.9%
Id = 21.1 %

Figure



Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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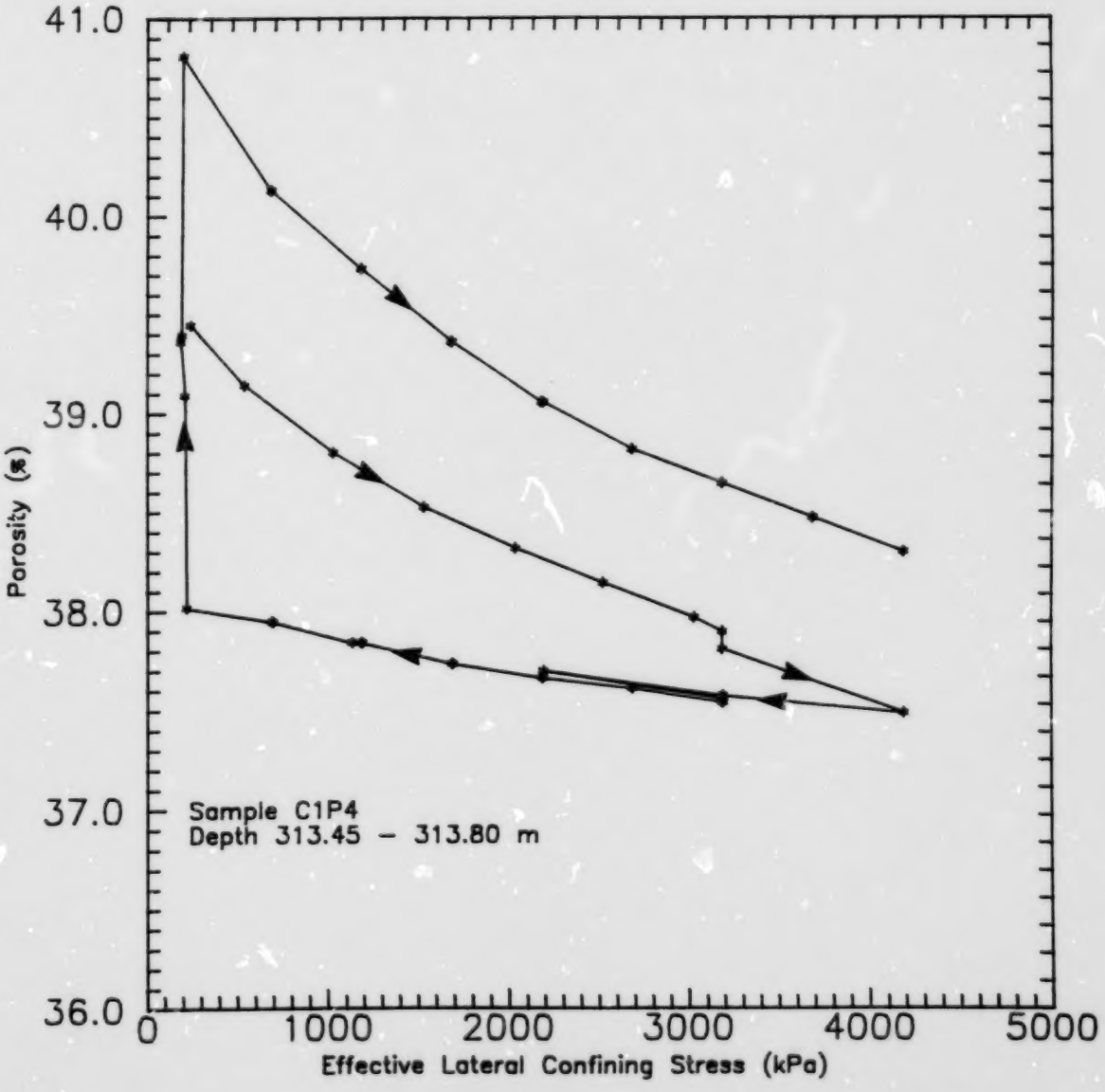
Figure



Task 2 – Porosity versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D1P972

DEPTH: 313.89 - 314.25 m

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 2

DATE TEST COMPLETED: 16 May 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #5 Sample was flushed with toluene followed by water. The sample was then placed under vacuum and refrozen. After refreezing sample, it was placed in triaxial cell for thawing under an effective confining stress of 200 kPa. #12 & #15 Back pressure was increased and decreased in 500 kPa increments.

#14 Sample was strained 12% at failure.

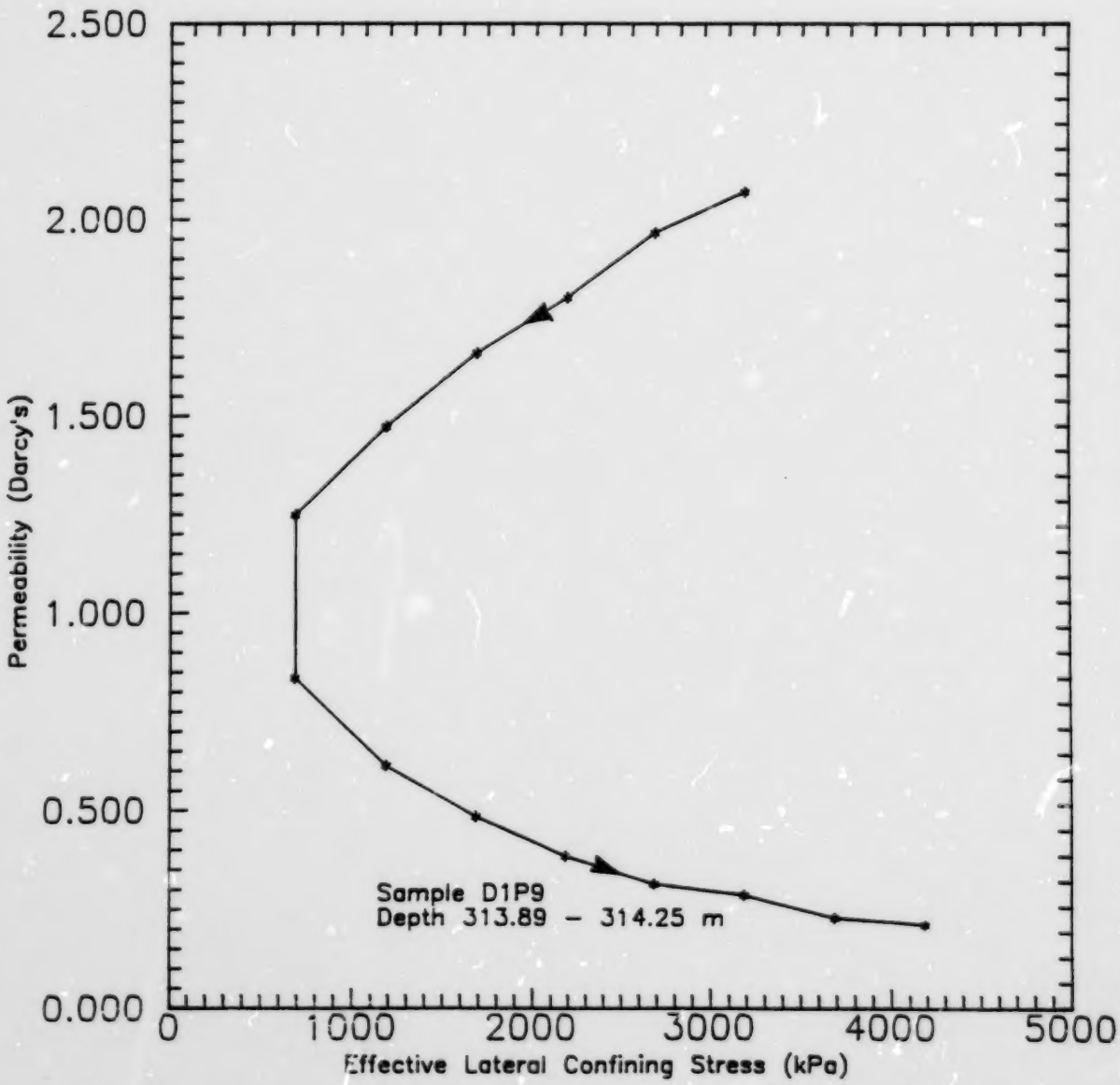
REMARKS: oil 17.5% water 1.5% solid 81.0%

sample density before extraction 1.70 g/cm3

in situ sample porosity 38.3%

Id = 26.3 %

Figure



Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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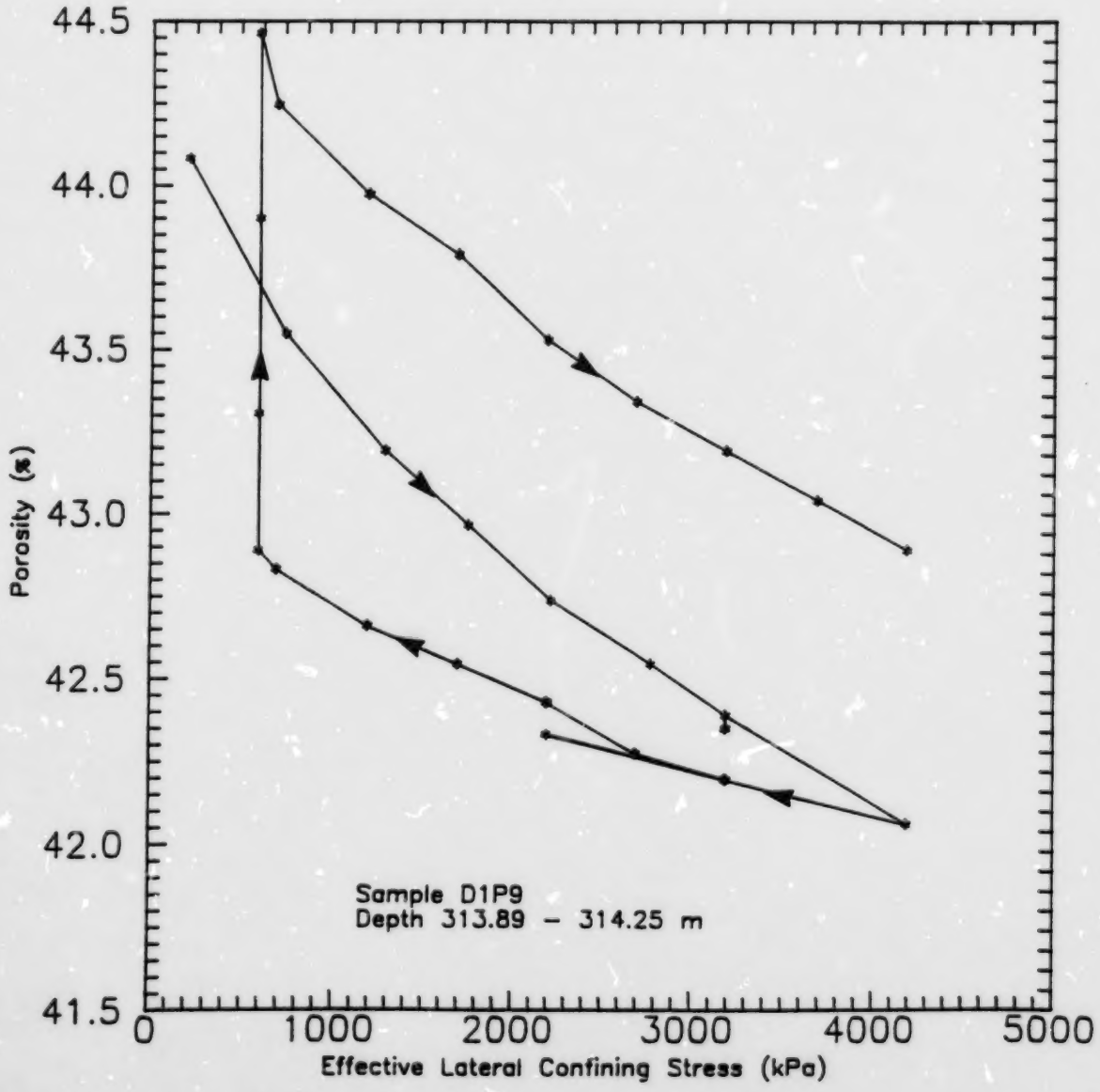
Figure



Task 2 – Porosity versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: B2P3T2

DEPTH: 308.47 - 308.82 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Test 2

DATE TEST COMPLETED: 09 March 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 05 Sample was flushed with Toluene followed by water. The sample was then placed under vacuum and refrozen. After refreezing sample, it was placed in triaxial cell for thawing under an effective confining stress of 200 kPa. 012 & 015 Back pressure was increased and decreased by 500 kPa in 250 Kpa increments.

REMARKS: oil 17.7% water 1.0% solid 81.3%

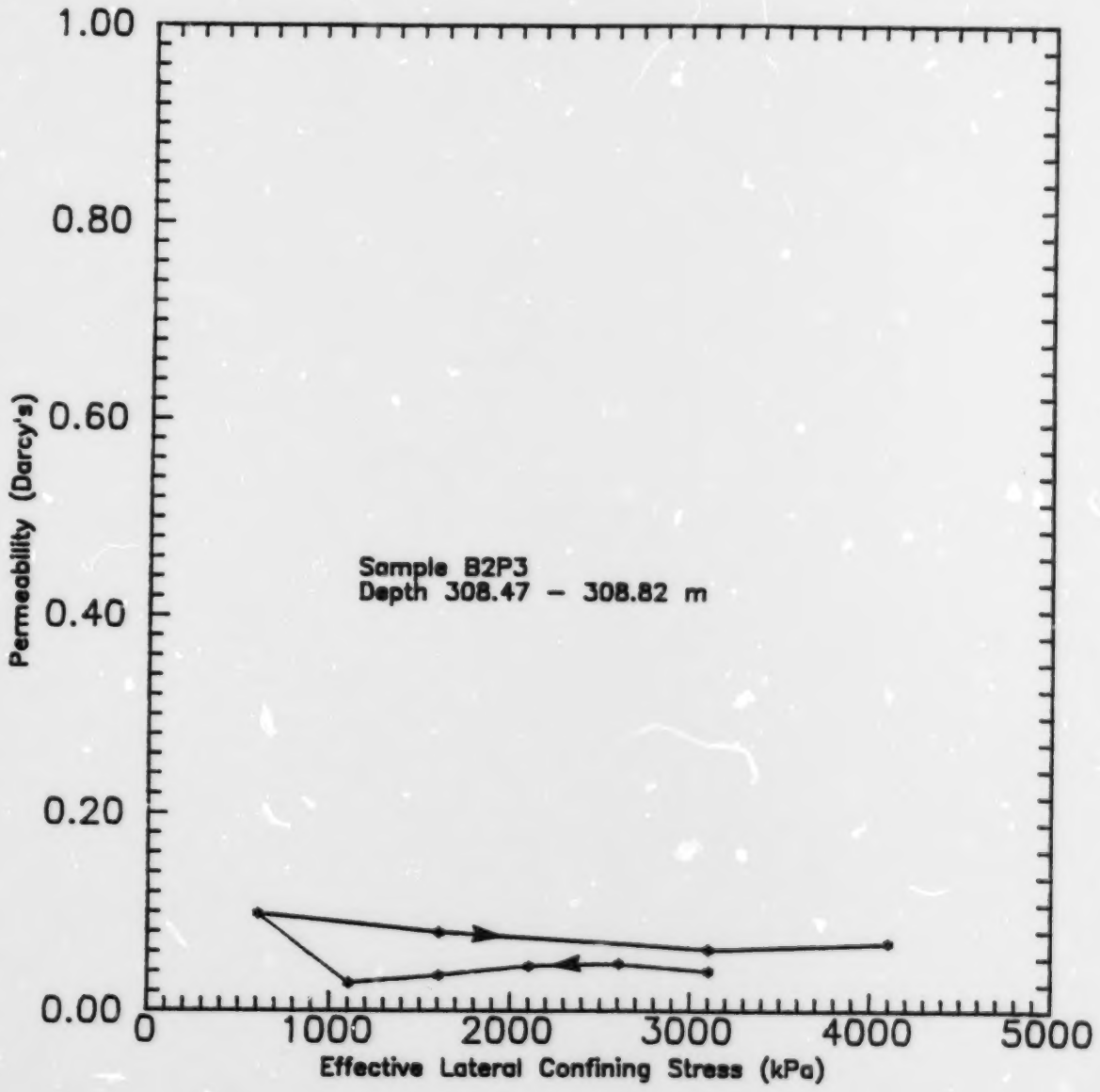
sample density before extraction 1.67 g/cm3

sample density after extraction 1.95 g/cm3

insitu sample porosity 37.0%

Id = 30.0%

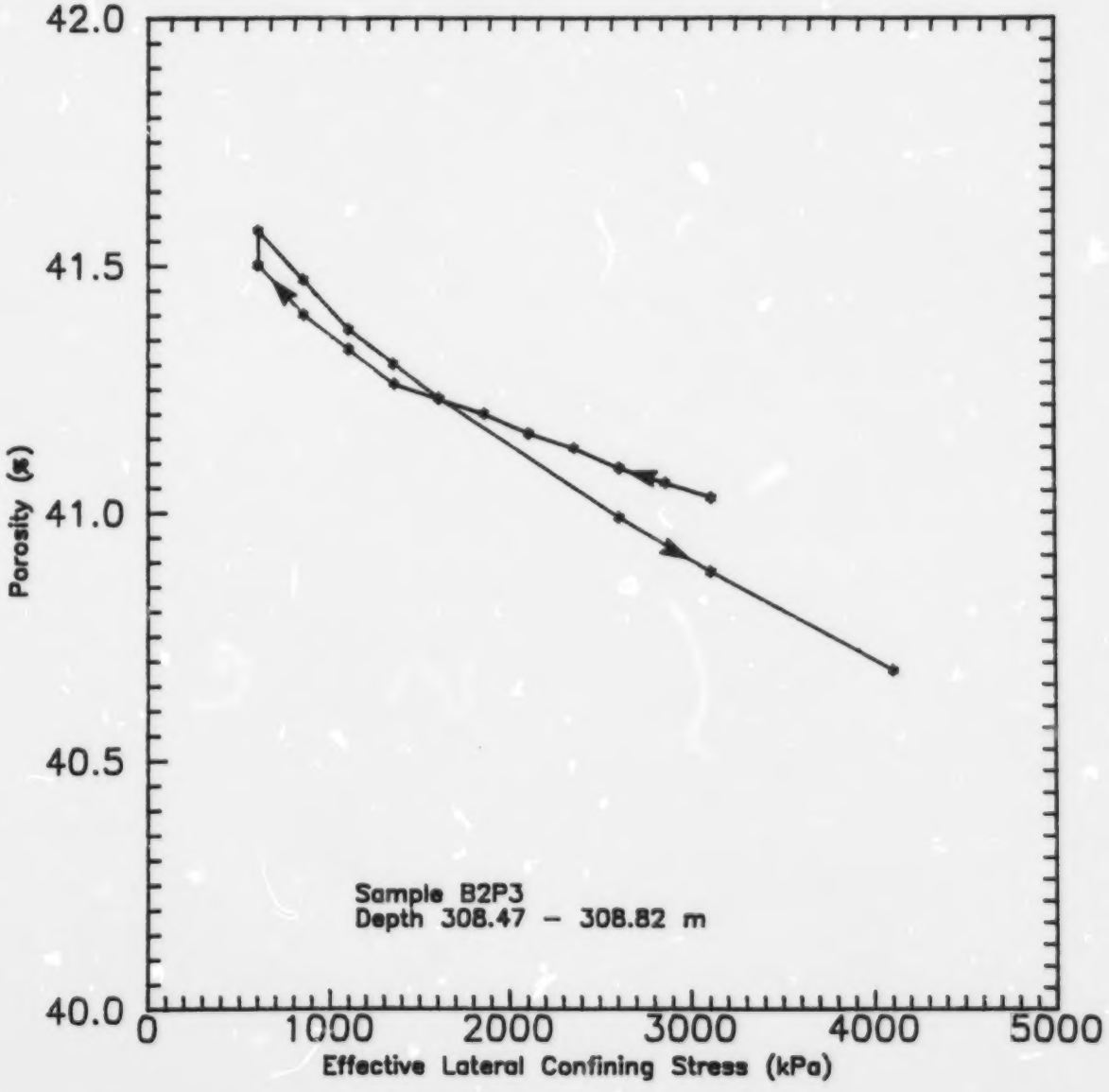
Figure



Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 2 – Porosity versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: B2P1?2

DEPTH: 296.86 - 297.22 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Test 2

DATE TEST COMPLETED: 01 May 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 05 Sample was flushed with toluene acetone then water. The sample was then placed under vacuum and refrozen. After refreezing sample, it was placed in triaxial cell for thaving under an effective confining stress of 200 kPa. 012 & 015 Back pressure was increased and decreased in 500 kPa increments. 014 Sample was strained 12% at failure. 017 Test was stopped 2 increments below in situ stress.

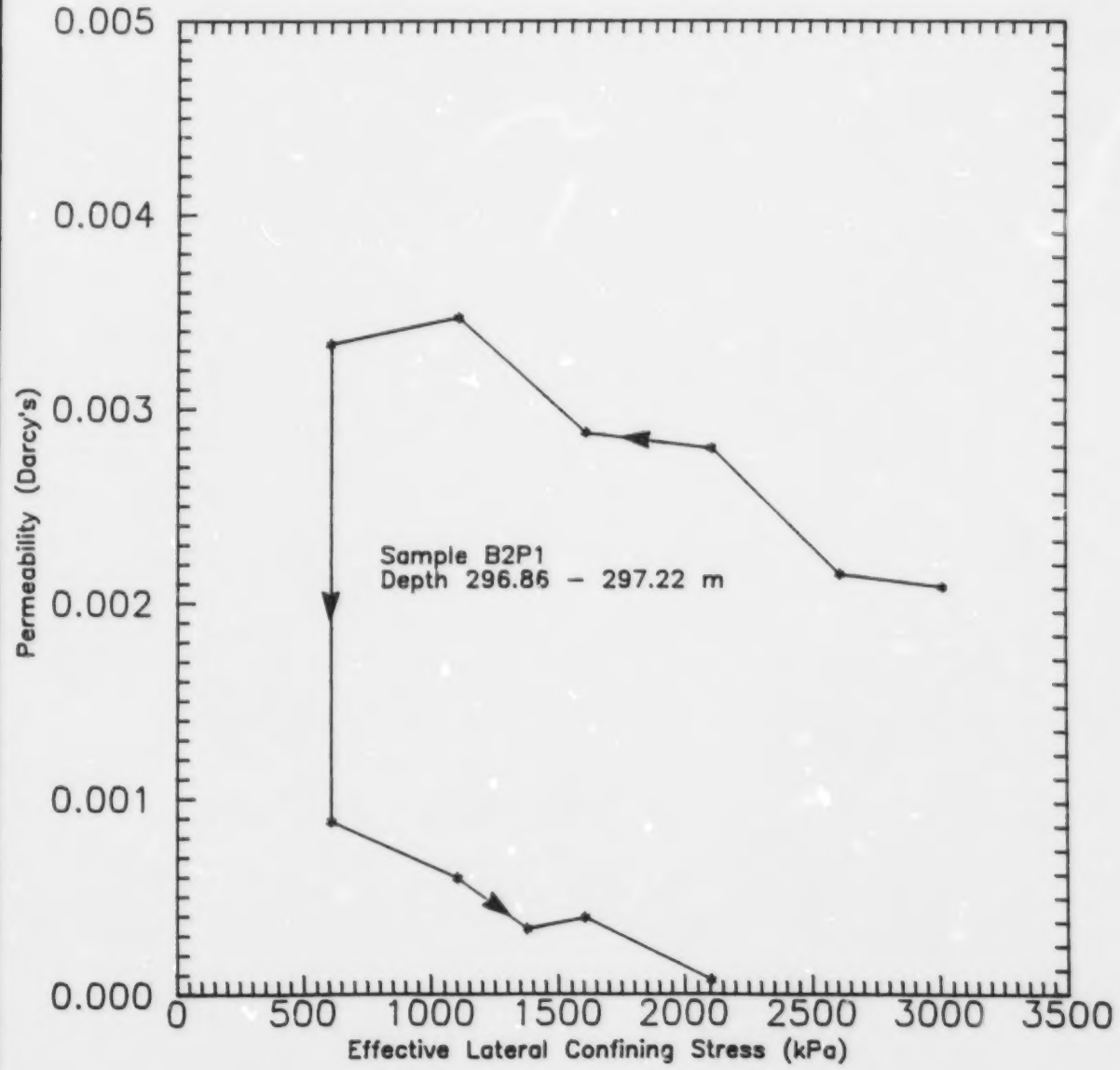
REMARKS: oil 15.4% water 3.1% solid 81.5%

sample density before extraction 2.00 g/cm3

in situ sample porosity 37.5%

Id = 3.9 %

Figure

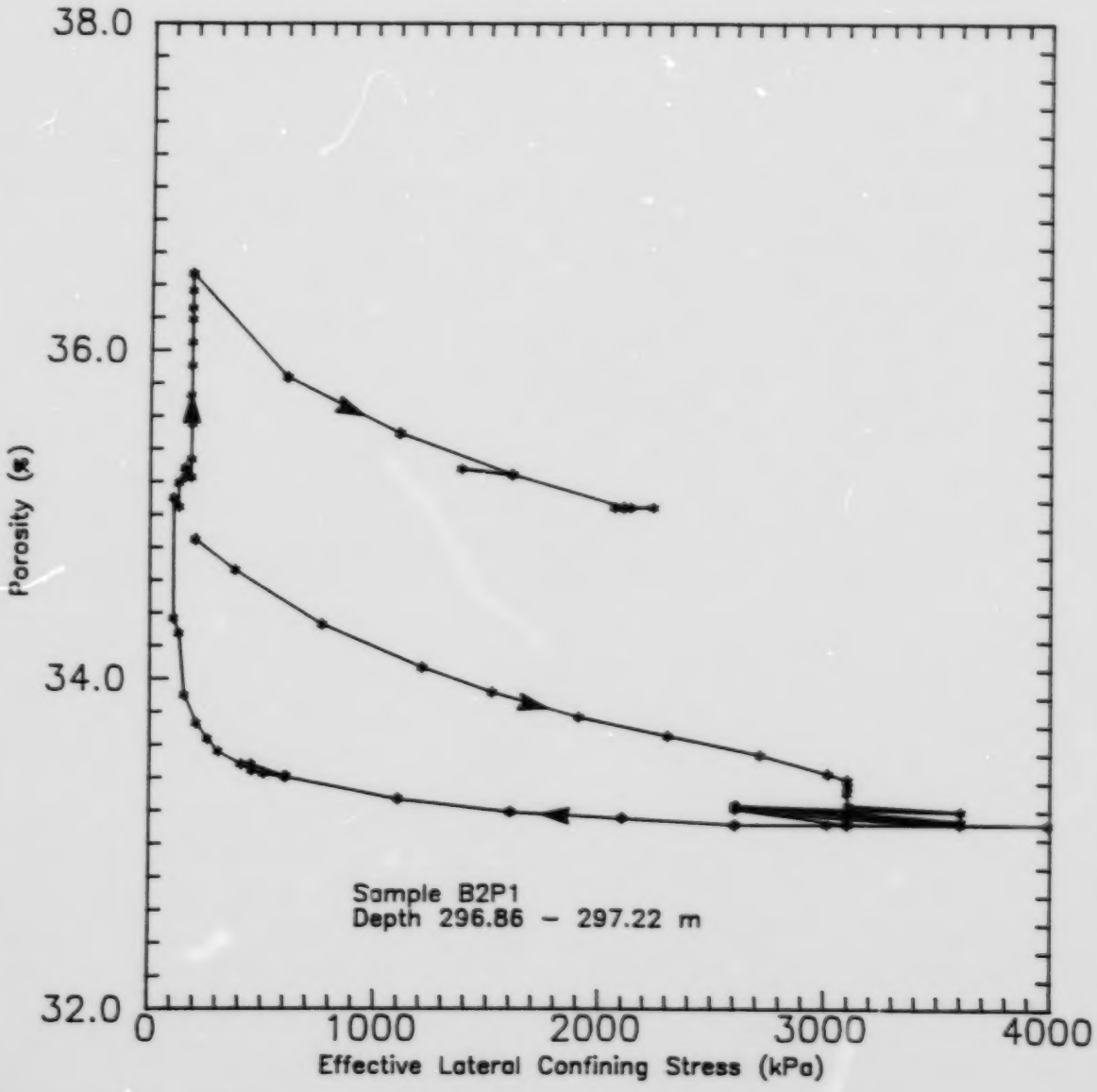


Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates

Figure



Task 2 – Porosity versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C1P2T2

DEPTH: 290.81- 291.16 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Extracted sample, some slight residual bitumen staining on one side of specimen

TYPE OF TEST: Task 2

DATE TEST COMPLETED: 10 May 1990

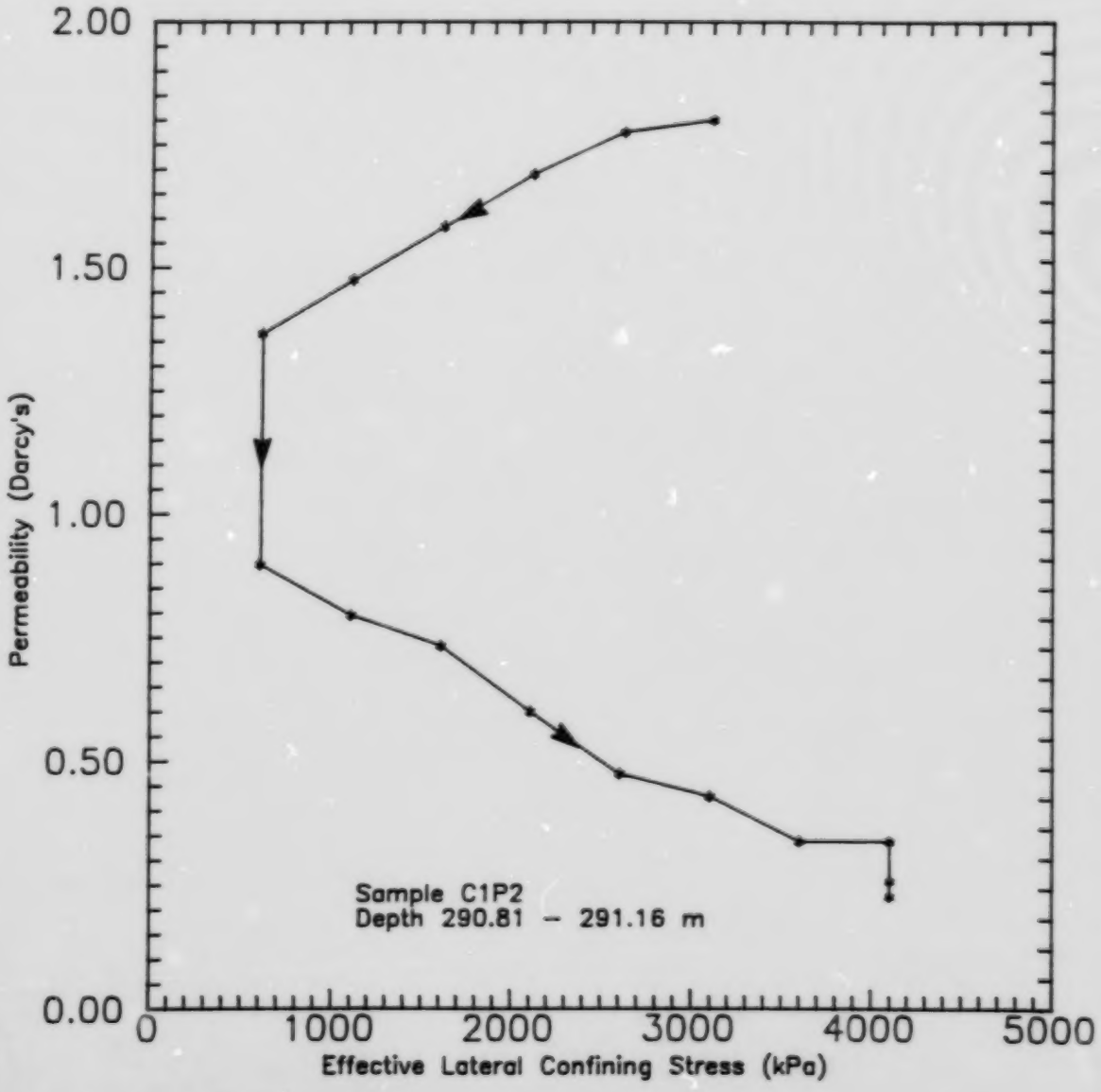
DEVIATIONS FROM STANDARD TEST PROCEDURE:

REMARKS: Prio to extraction: water 2.65% by mass

bitumen 16.23 % by mass

solids 81.12 % by mass

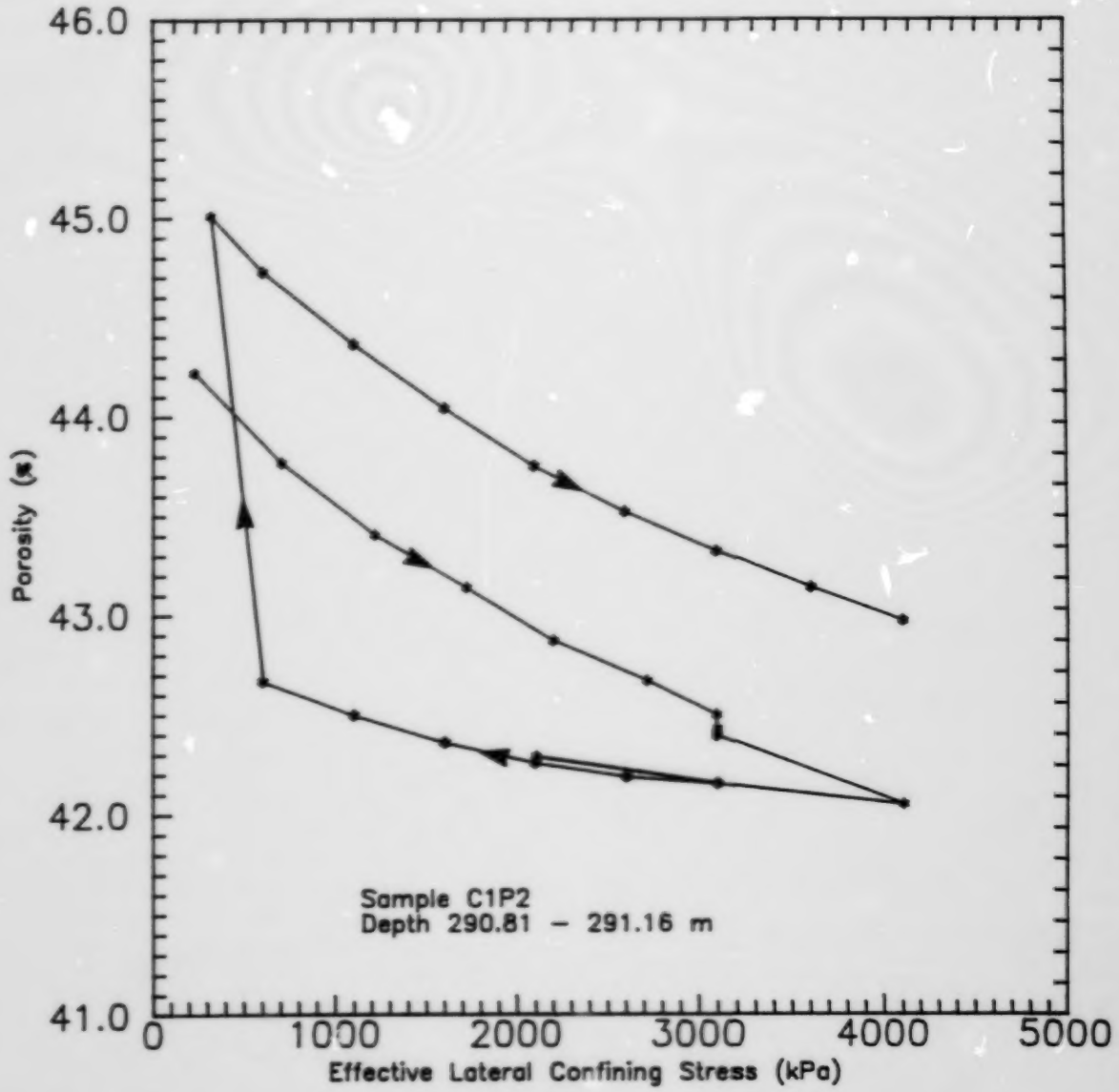
Figure



Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 2 – Porosity versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C3P2T2

DEPTH: 328.20 - 328.61 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Medium Oil Sand

TYPE OF TEST: Task 2

DATE TEST COMPLETED: 15 May 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #5 Sample was flushed with toluene followed by water. The sample was then placed under vacuum and refrozen. After refreezing sample, it was placed in triaxial cell for thawing under an effective confining stress of 200 kPa. #12 & #15 Back pressure was increased and decreased in 500 kPa increments. #14 Sample was strained 12% at failure.

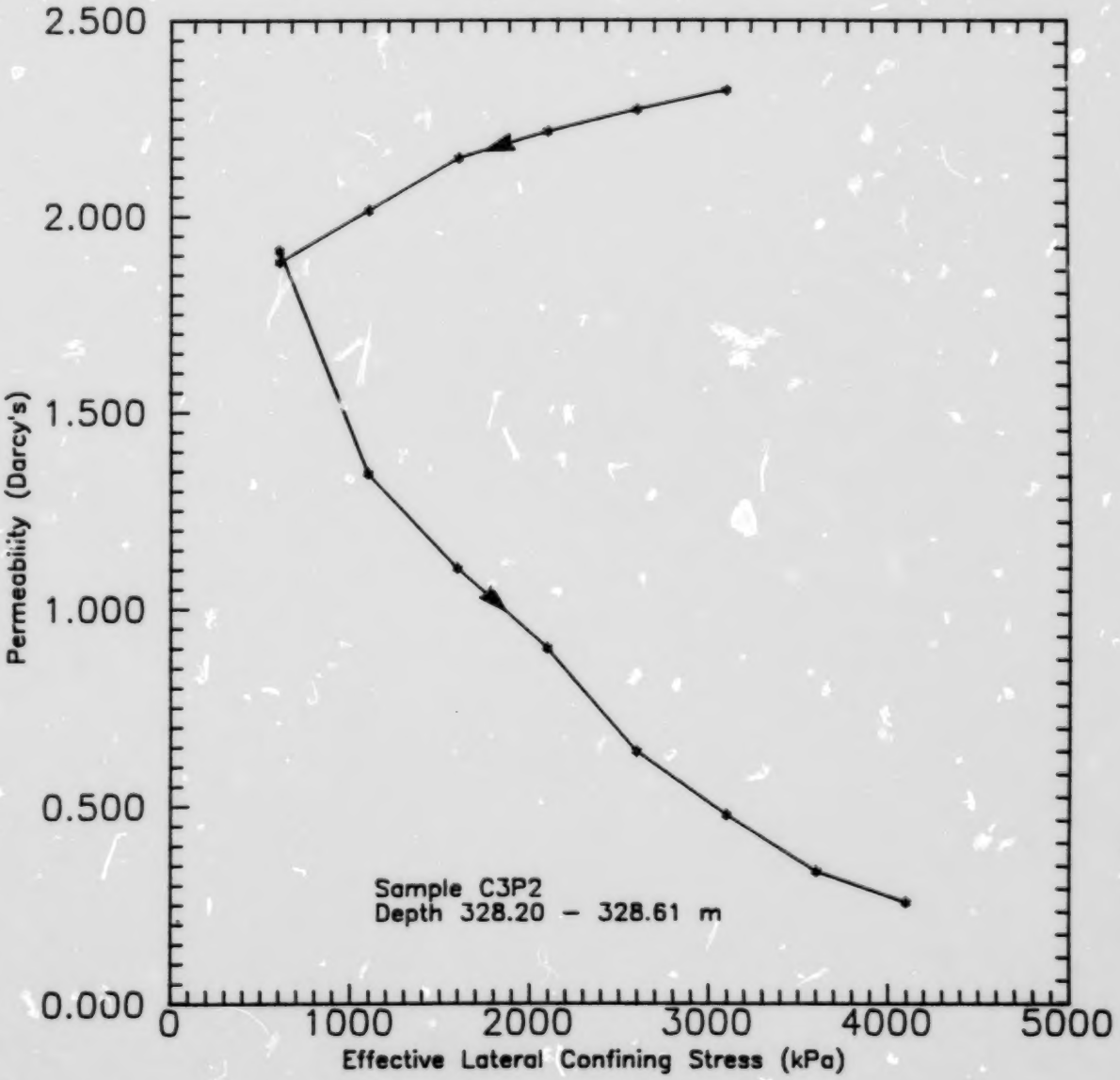
REMARKS: oil 9.1% water 3.5% solid 87.4%

sample density before extraction 1.82 g/cm3.

In situ sample porosity 27.6%

Id = 46.5 %

Figure



Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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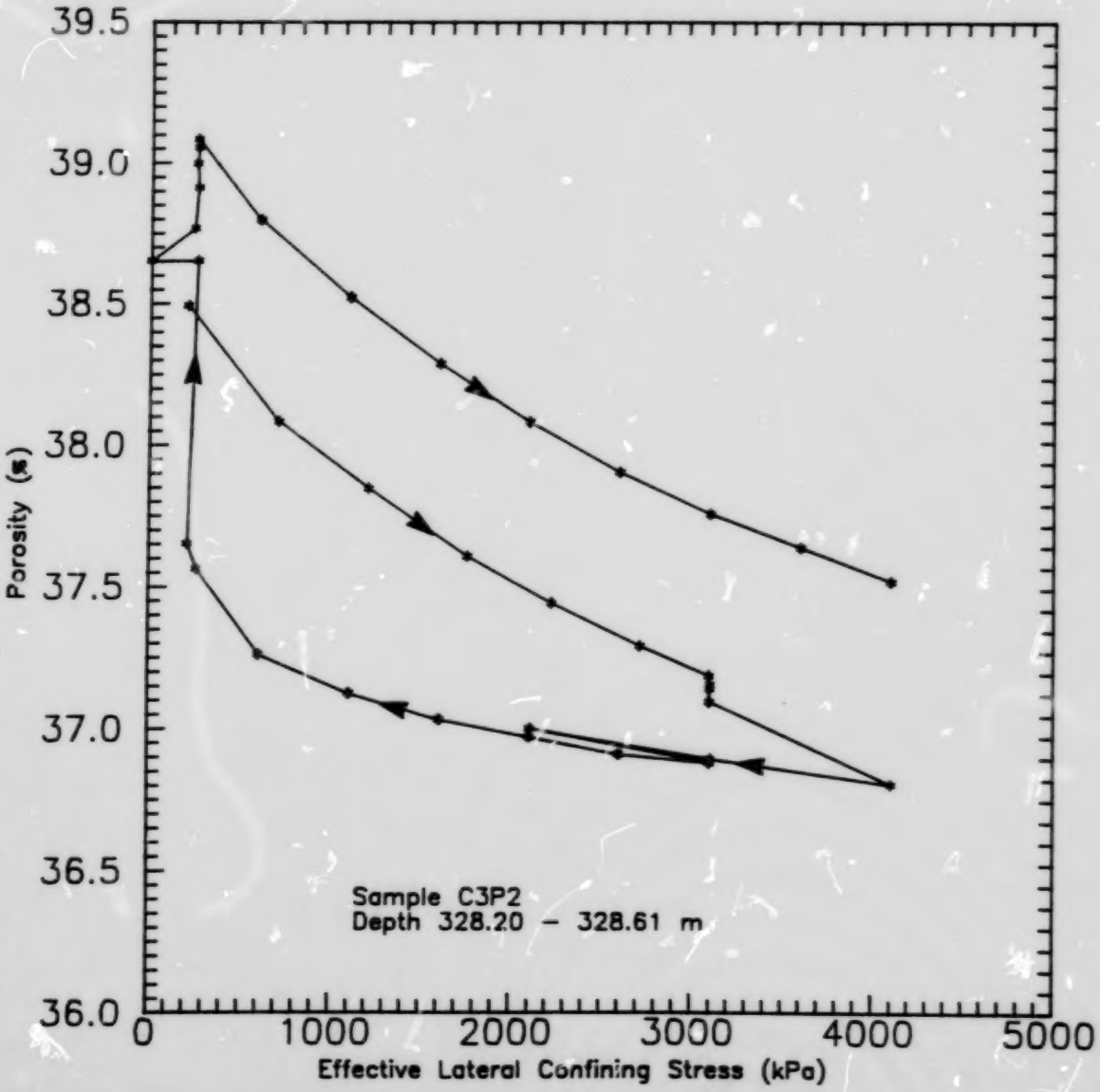
Figure



Task 2 – Porosity versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C3P3T2

DEPTH: 328.99 - 329.37

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Medium oil sand, poor sample, cracking.
Touched up one end of sample in two places with wax.

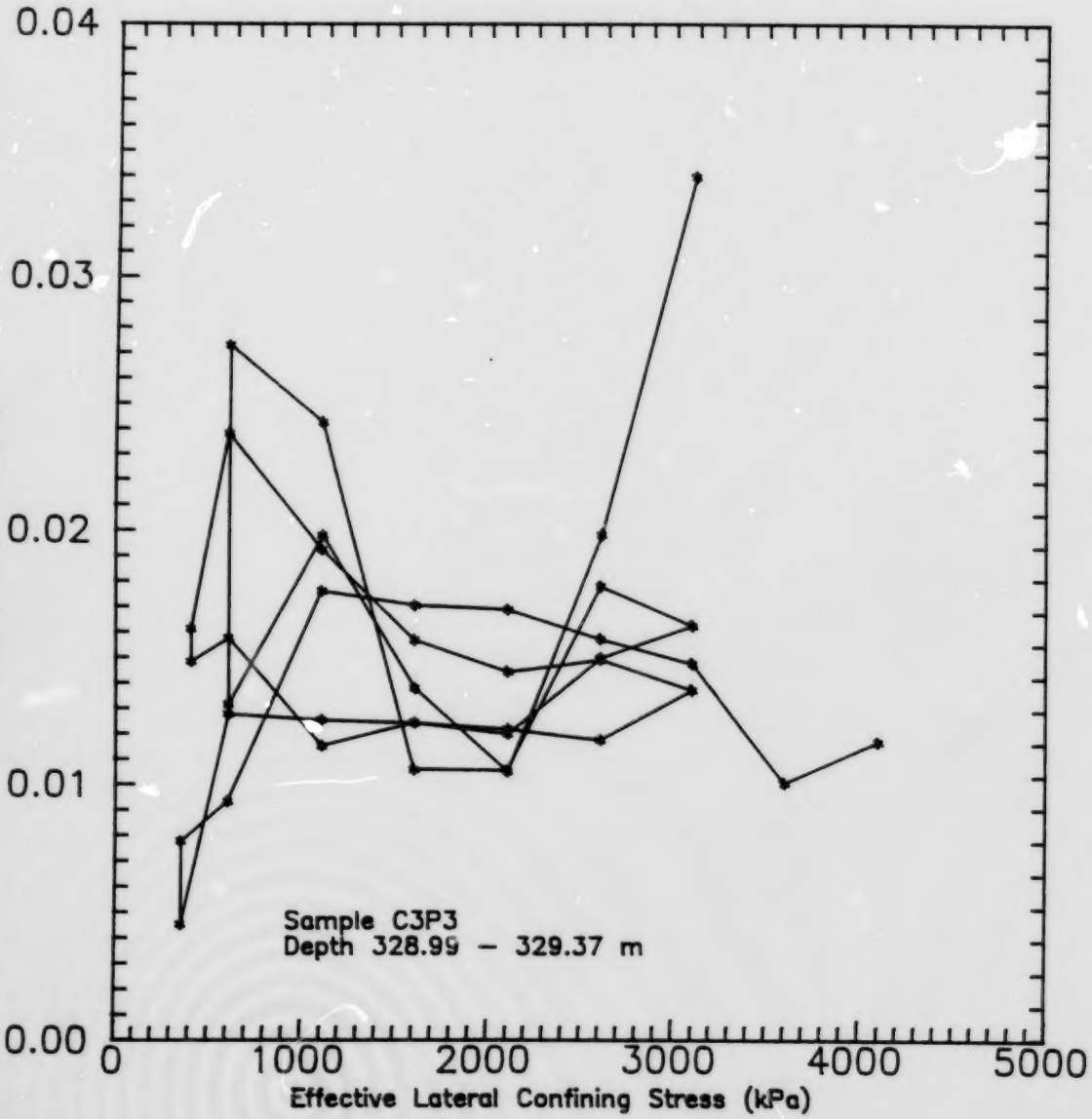
TYPE OF TEST: Task 2 no bitumen removal, 3 cycles

DATE TEST COMPLETED: 1 August 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 Effective confining stress = 200 kPa
05,6 Do not flush bitumen from sample.
012,15 Cell pressure was decreased and increased in 500 kPa increments, back pressure was held constant.
014 Sample was strained 6% at failure envelope.
017 Repeat steps 11 to 17 twice for a total of three cycles.
Repeat steps 12 and 13 to insitu stress for first two cycles, and to 1 MPa above insitu for the third cycle.

REMARKS: oil 12.7% water 2.0% solid 85.3% (by mass)
porosity before testing 43.5%
porosity in situ 31.3%
(porosity is defined as ratio of void volume to total volume)
index of disturbance 39.0%

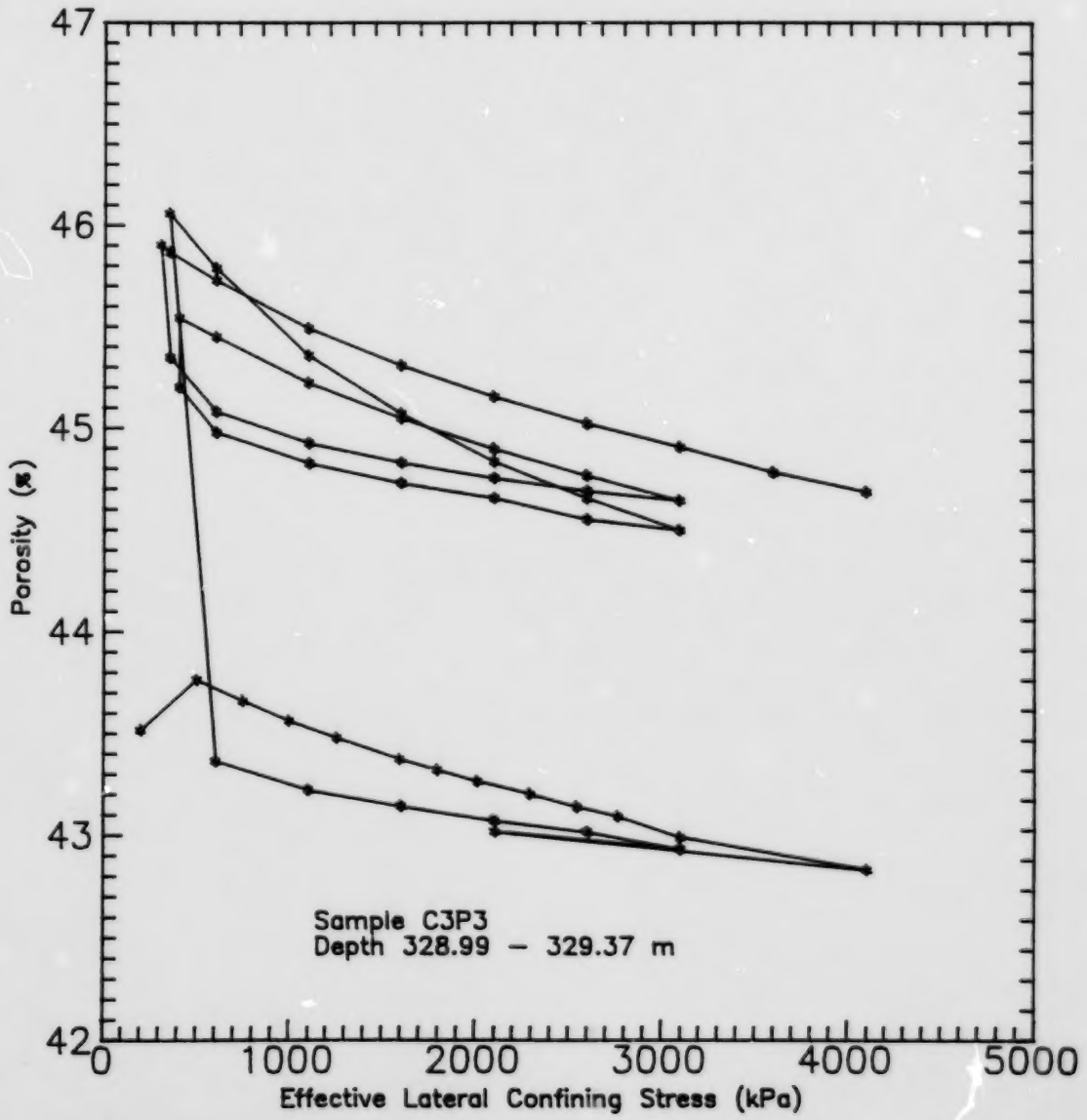
Figure



Task 2 – Permeability versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 2 – Porosity versus Effective Lateral Confining Stress

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

APPENDIX IV - TASK 3 TEST RESULTS

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: 81P8T3

DEPTH: 316.75 - 317.10

GEOLOGICAL UNIT: Lower Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 3

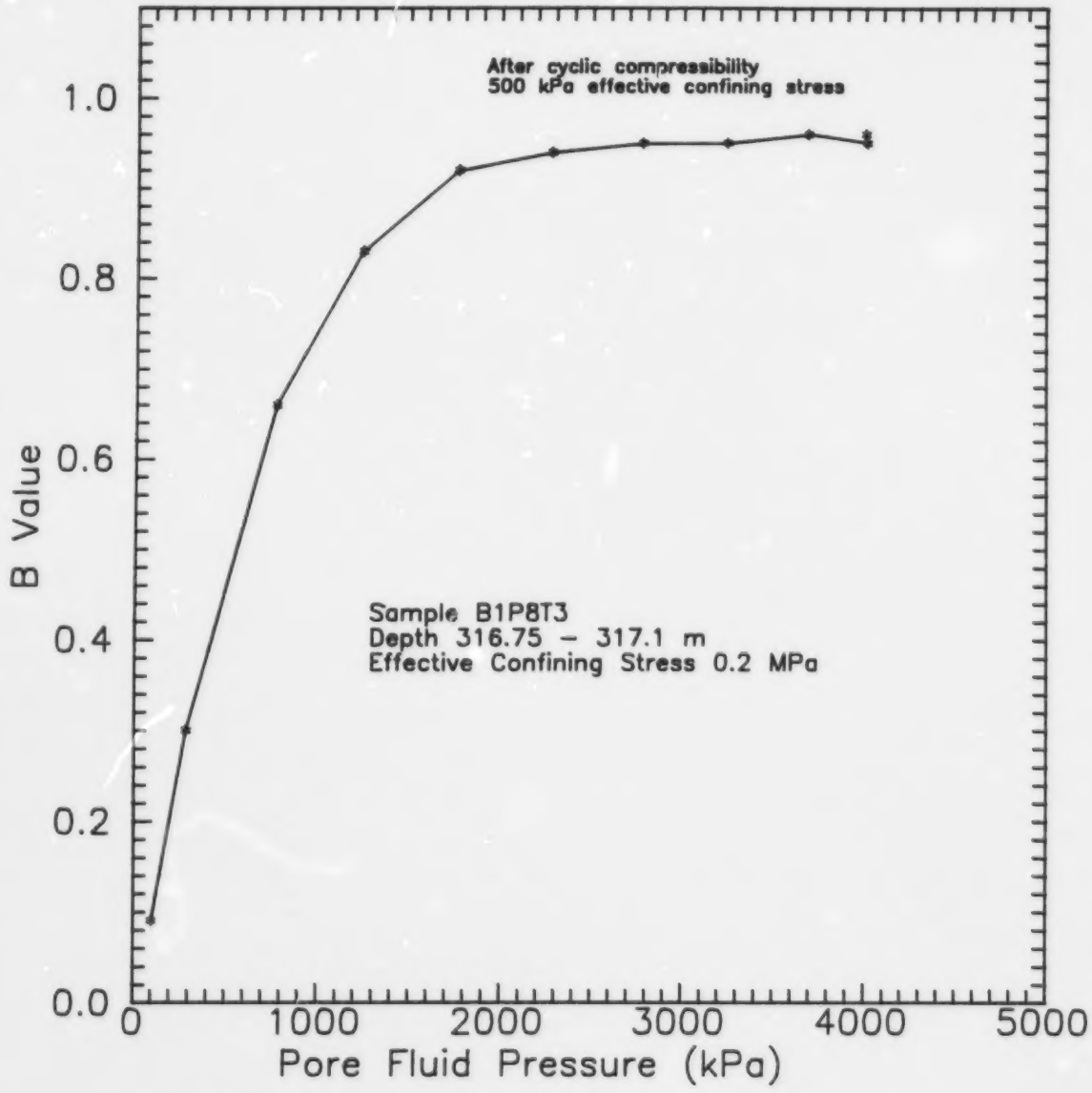
DATE TEST COMPLETED: 19 January 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic Stress conditions with effective confining stress equal to in situ horizontal effective stress

REMARKS:

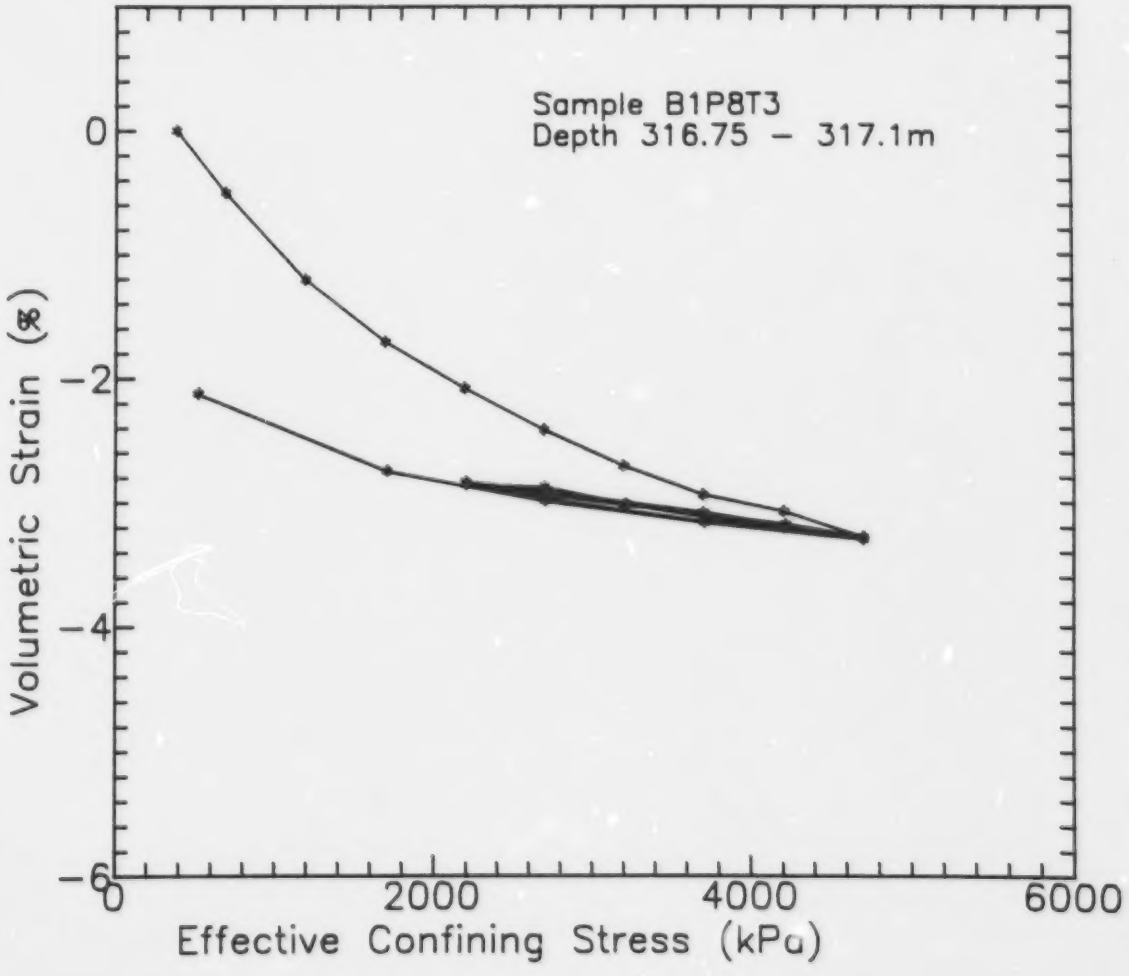
Figure



Task 3 – Pore Pressure Parameter B Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

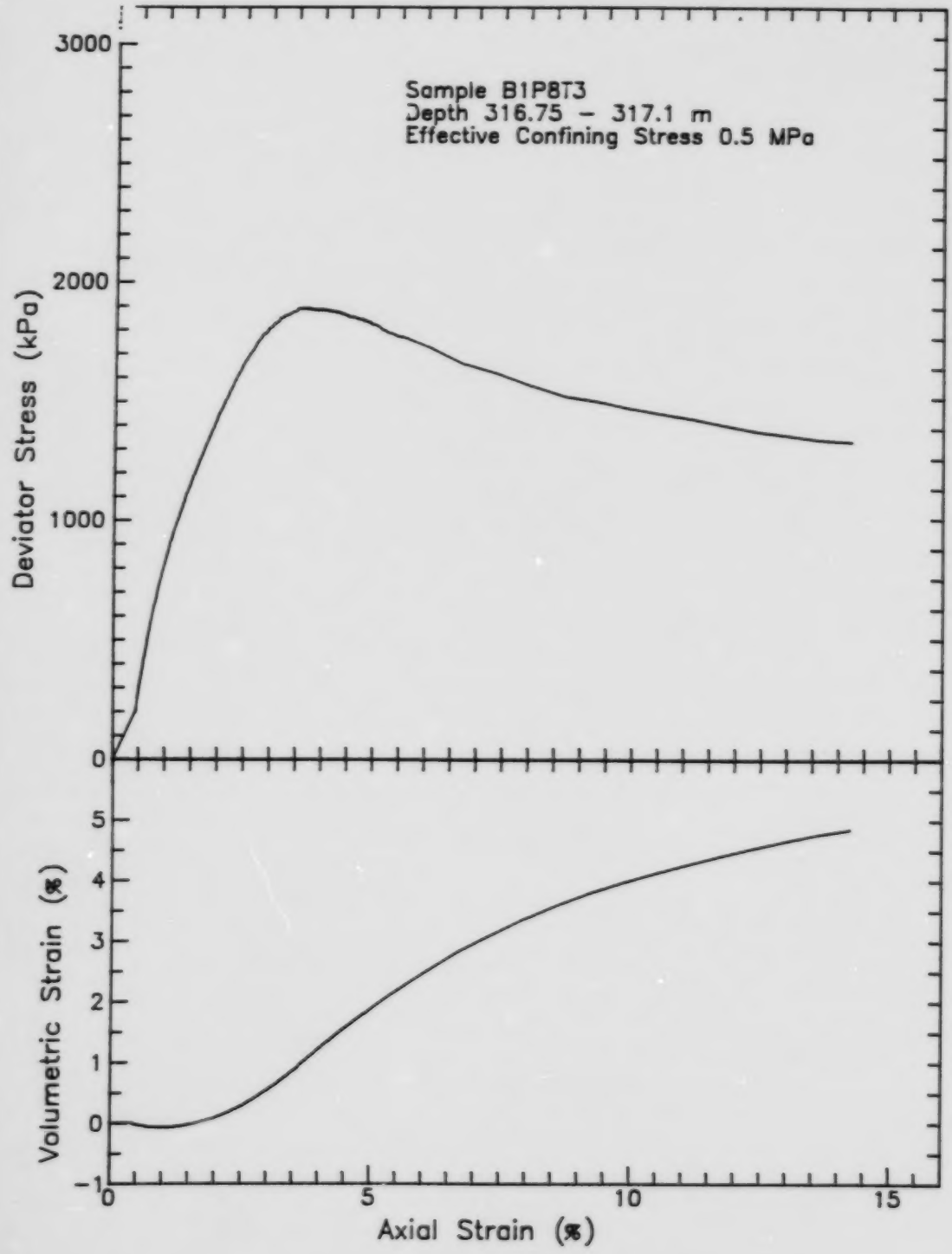
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ____C1P4_____

DEPTH: ____313.45 - 313.80_____

GEOLOGICAL UNIT: __Lower Sand_____

VISUAL DESCRIPTION:_Rich Oil Sand, Some visible cracking on sample_____

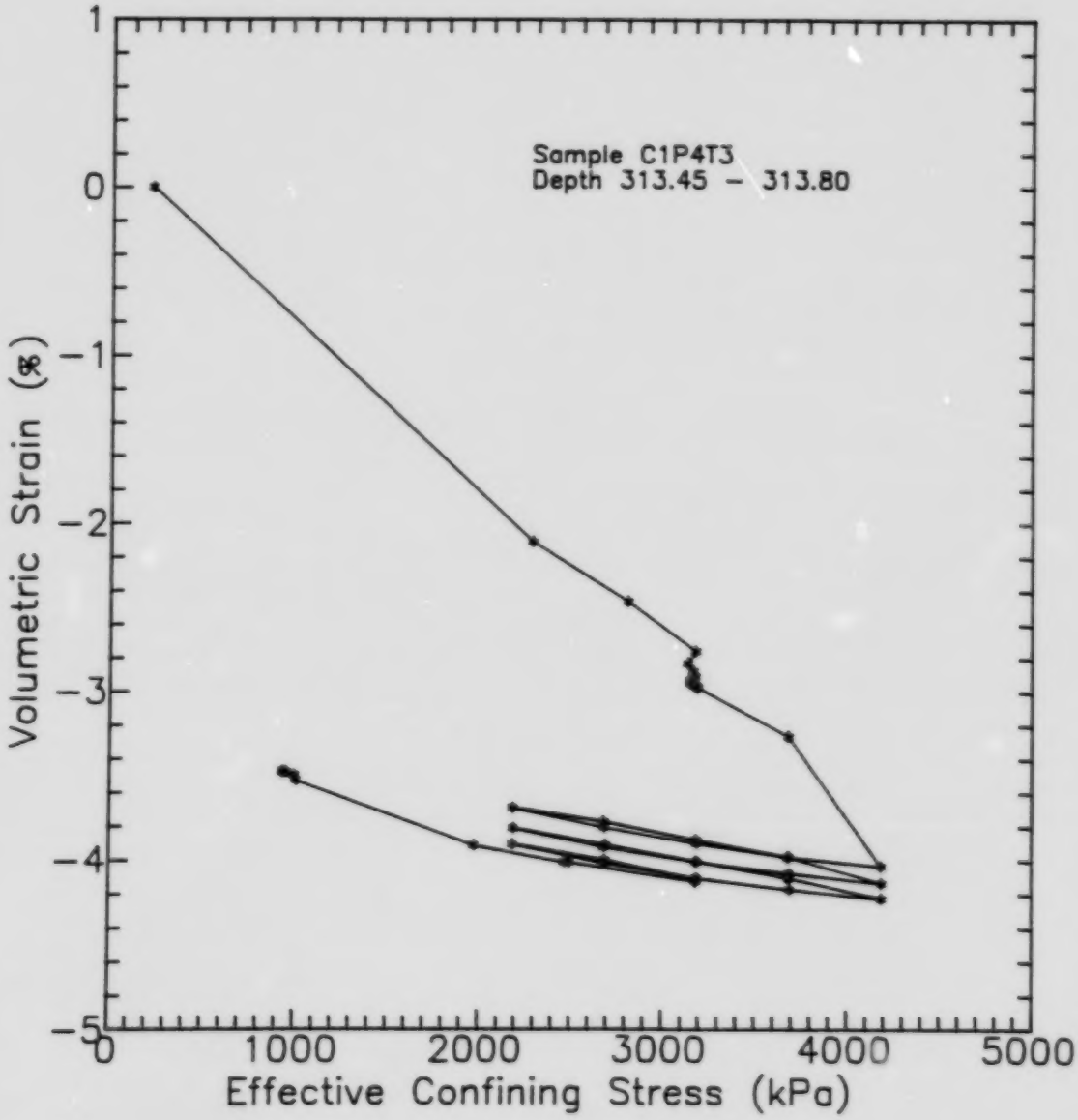
TYPE OF TEST: __Task 3_____

DATE TEST COMPLETED: _4 May 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _#4 and #5____Effective confining stress = 200 kPa_____

REMARKS:_____

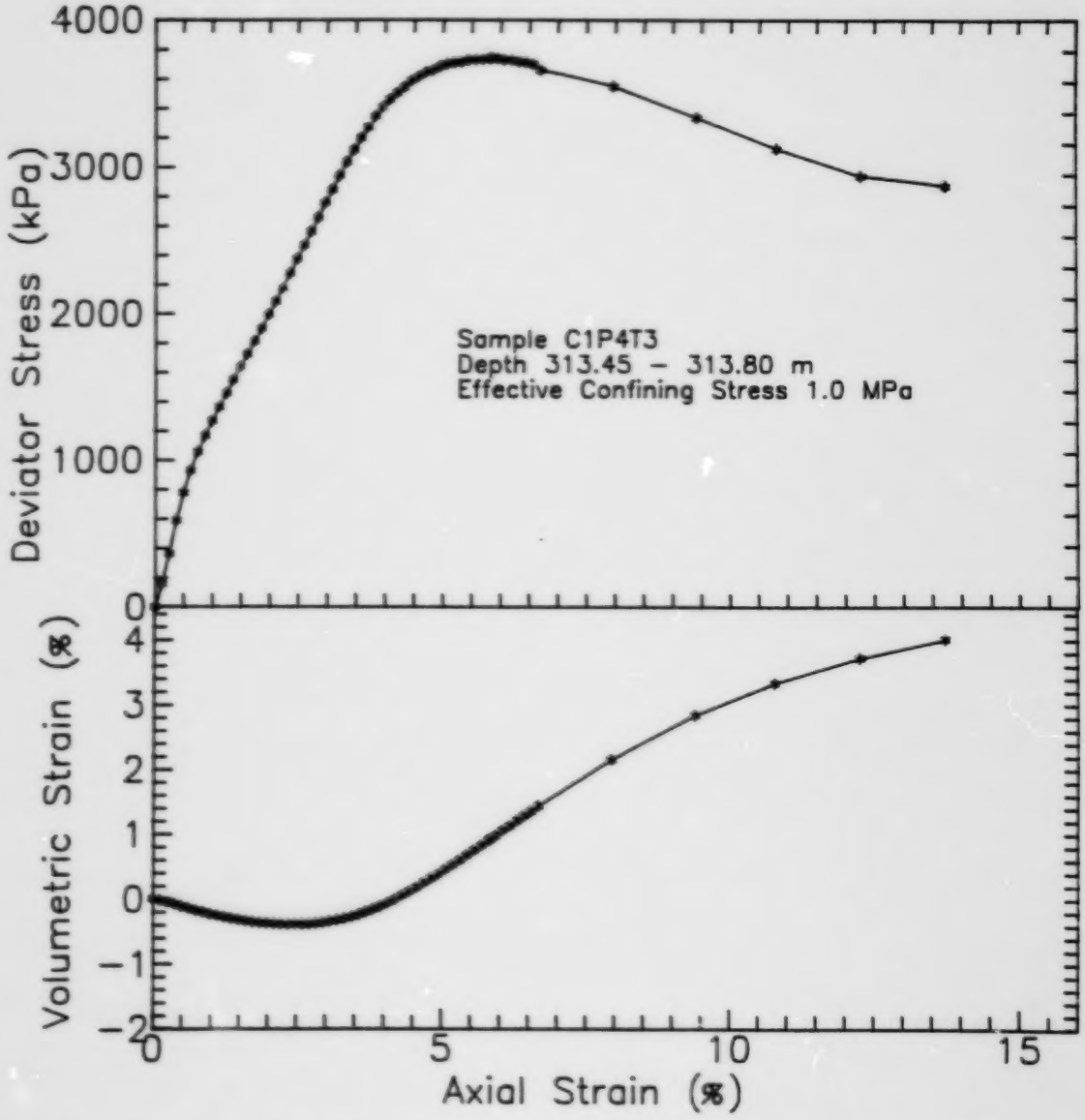
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ____B2P7T3_____

DEPTH: ____329.20 - 329.55_____

GEOLOGICAL UNIT: __Lower Sand_____

VISUAL DESCRIPTION: _Rich Oil Sand_____

TYPE OF TEST: __Task 3_____

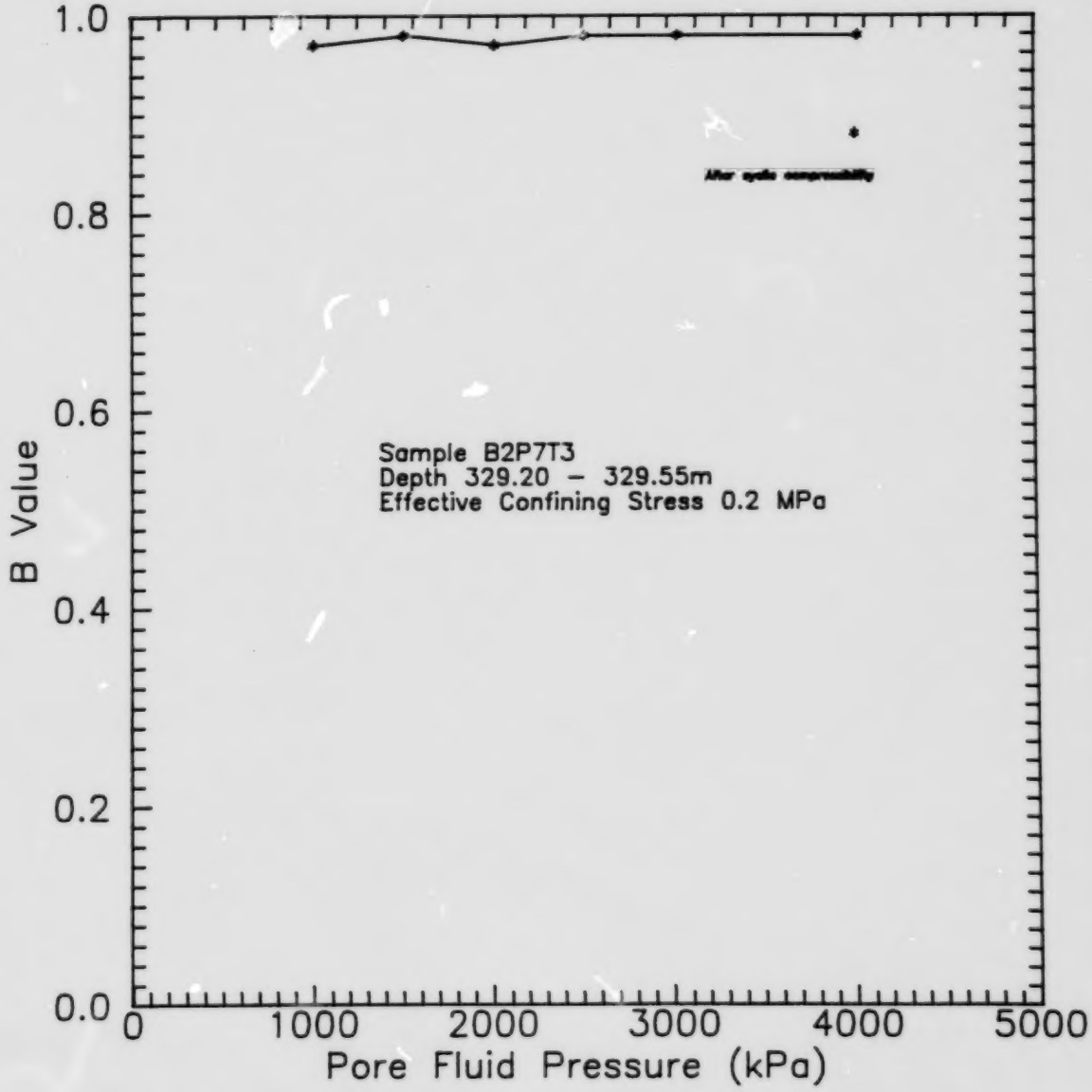
DATE TEST COMPLETED: _23 April 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _#4 and #5____Effective confining stress = 200 kPa_____

_#5,6 and 7 steps repeated twice_____

REMARKS:_____

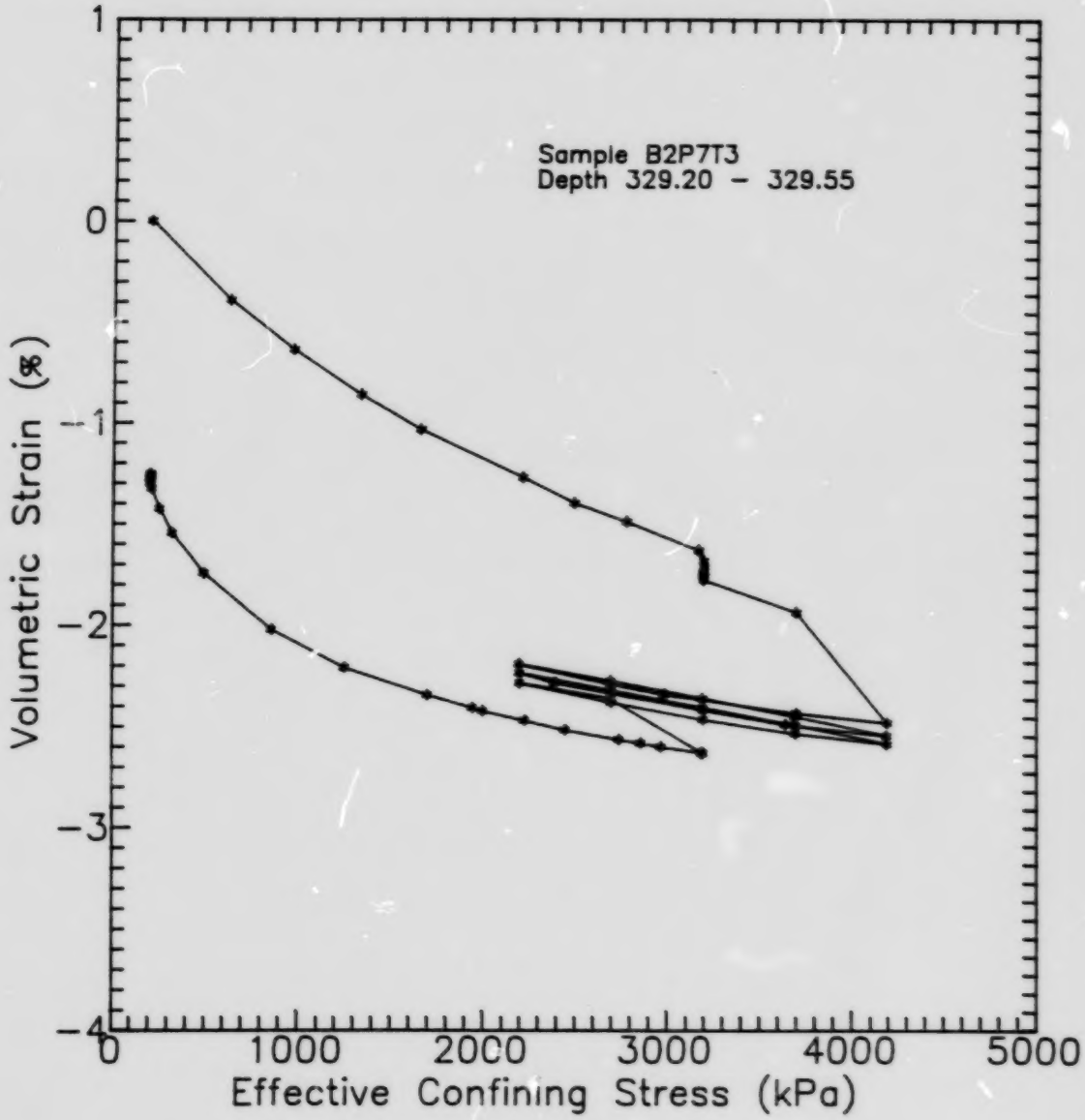
Figure



Task 3 – Pore pressure Parameter B Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

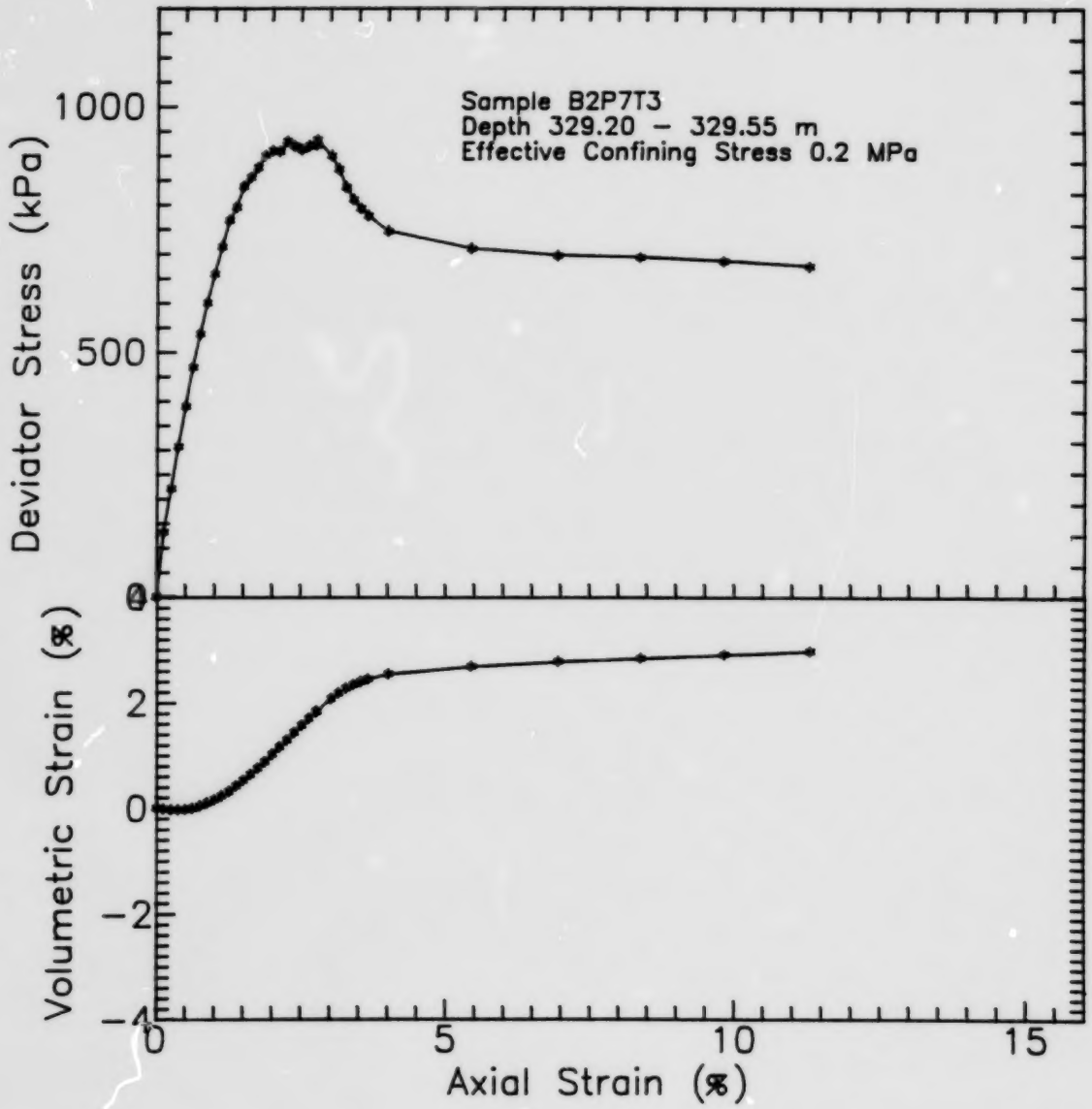
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: B1P4T3

DEPTH: 295.60 - 296.03

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 3

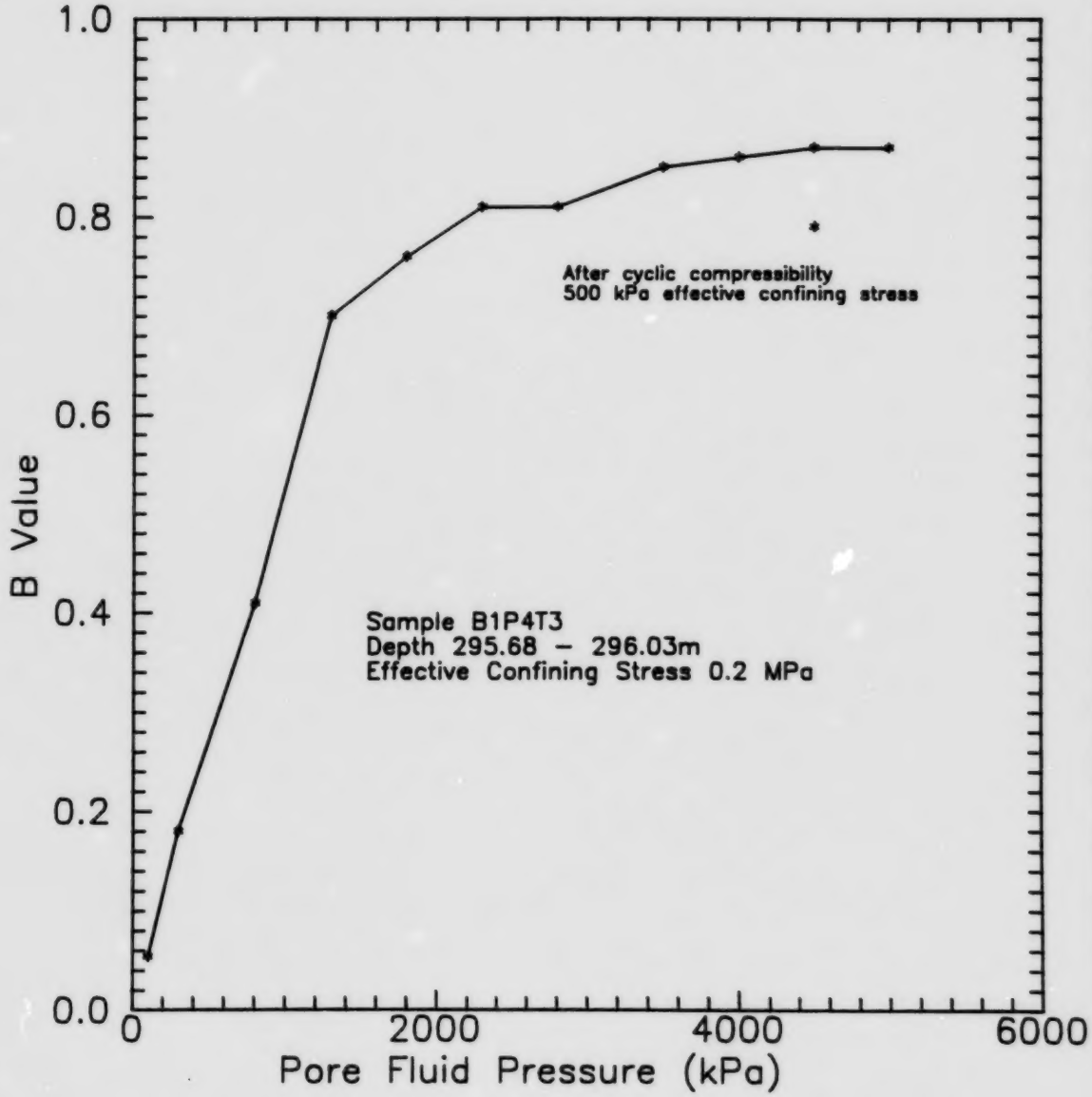
DATE TEST COMPLETED: 02 February 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic Stress conditions with effective confining stress equal to in situ horizontal effective stress

REMARKS:

Figure



Task 3 – Pore Pressure Parameter B Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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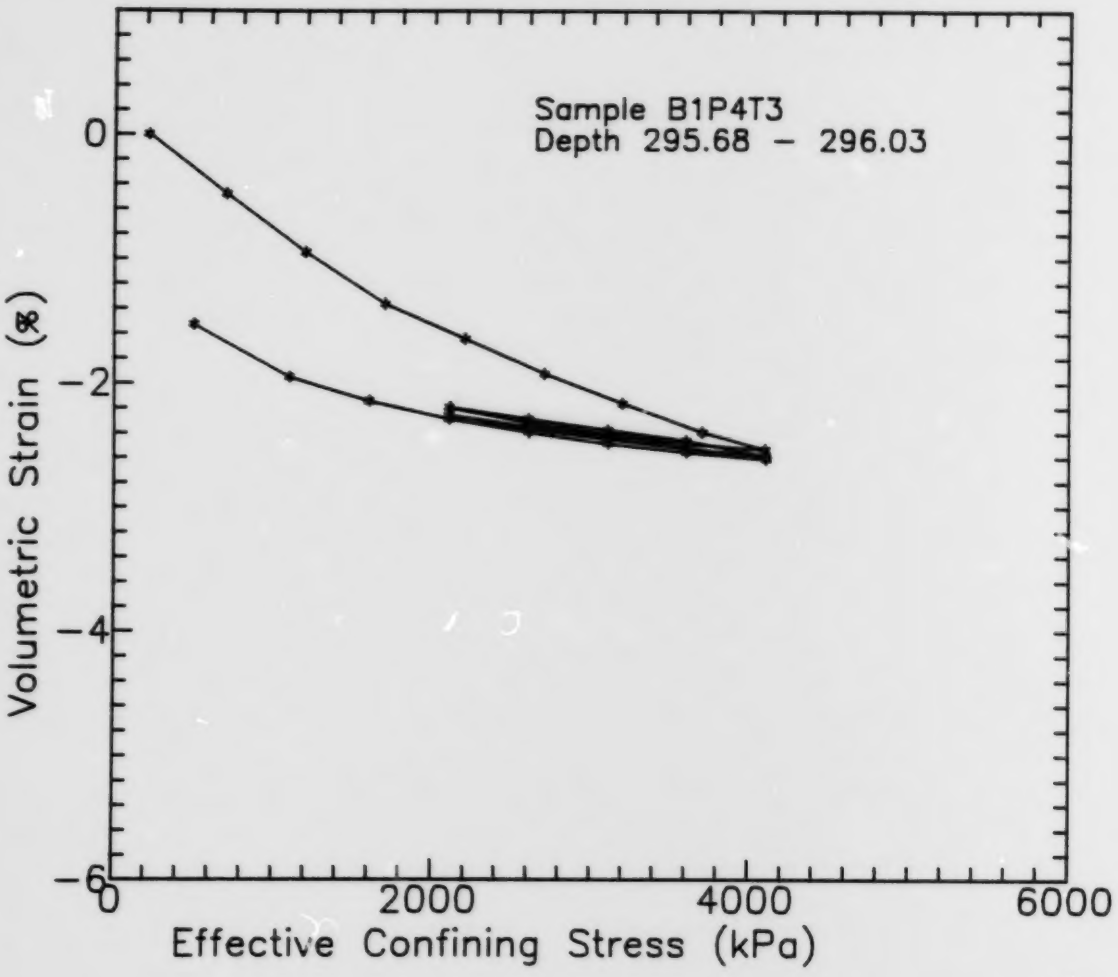
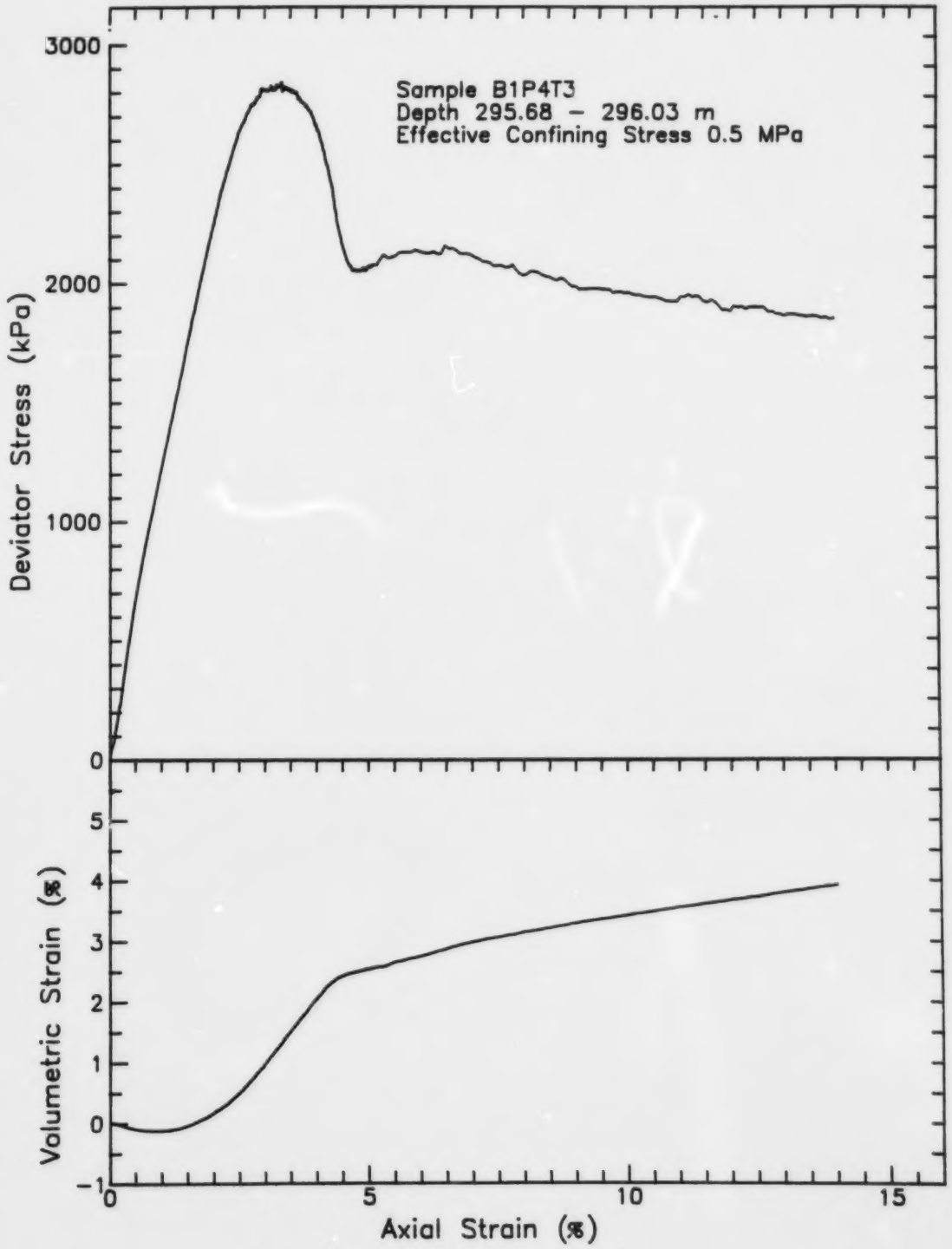
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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CONSULTING ENGINEERS

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C1P2T3

DEPTH: 290.81 - 291.16

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich oil sand, poor sample, oblong, external cracking, much disturbance

TYPE OF TEST: Task 3

DATE TEST COMPLETED: August 3, 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 mPa above in situ confining stress (3104 + 1000 kPa).

07 Reduce radial effective stress to 1 mPa below in situ confining stress (3104 - 1000 kPa) allowing consolidation.

REMARKS: oil 16.2% water 2.7% solid 81.1% (by mass)

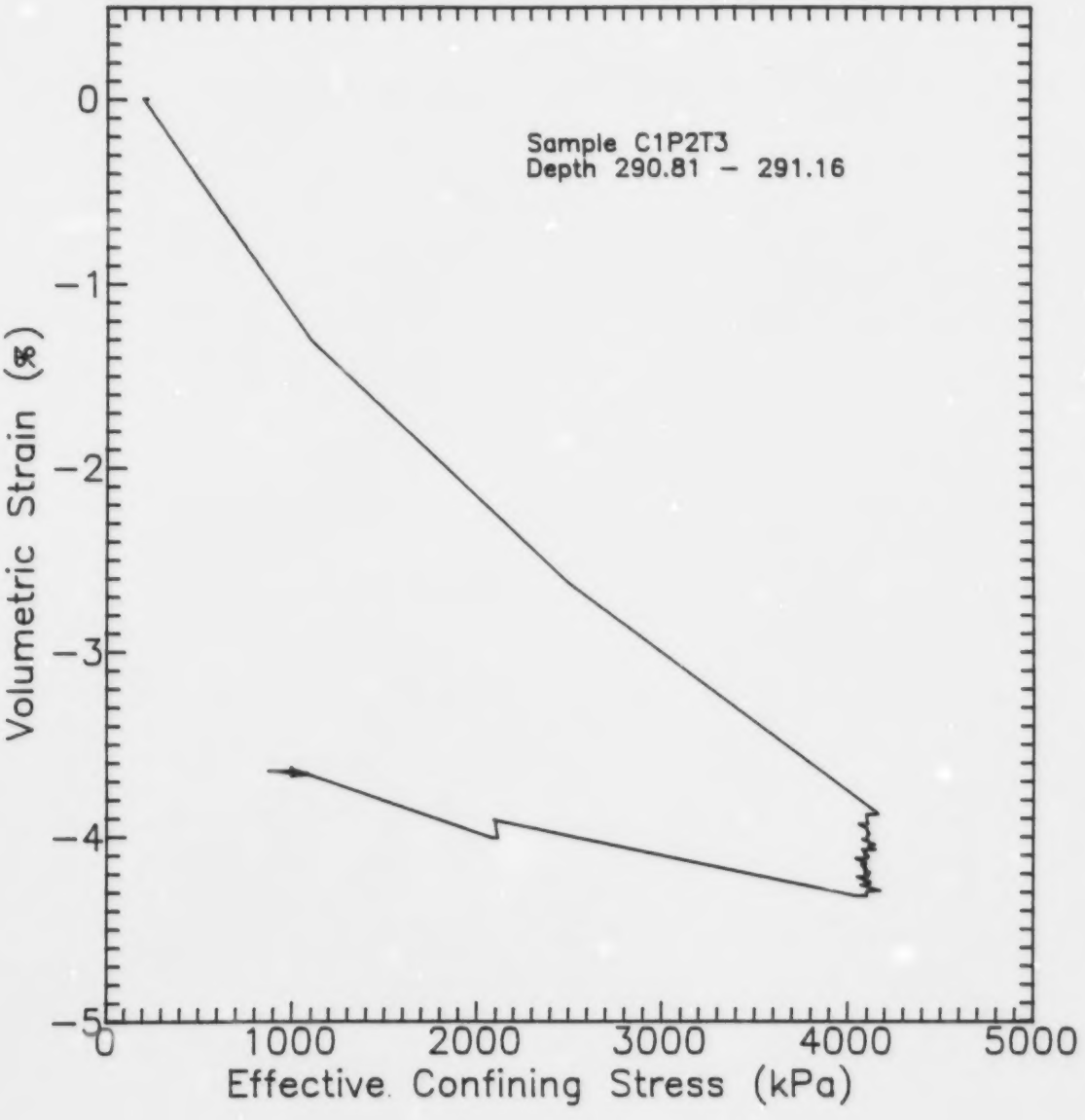
porosity before testing 49.0%

porosity in situ 38.1%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 28.5%

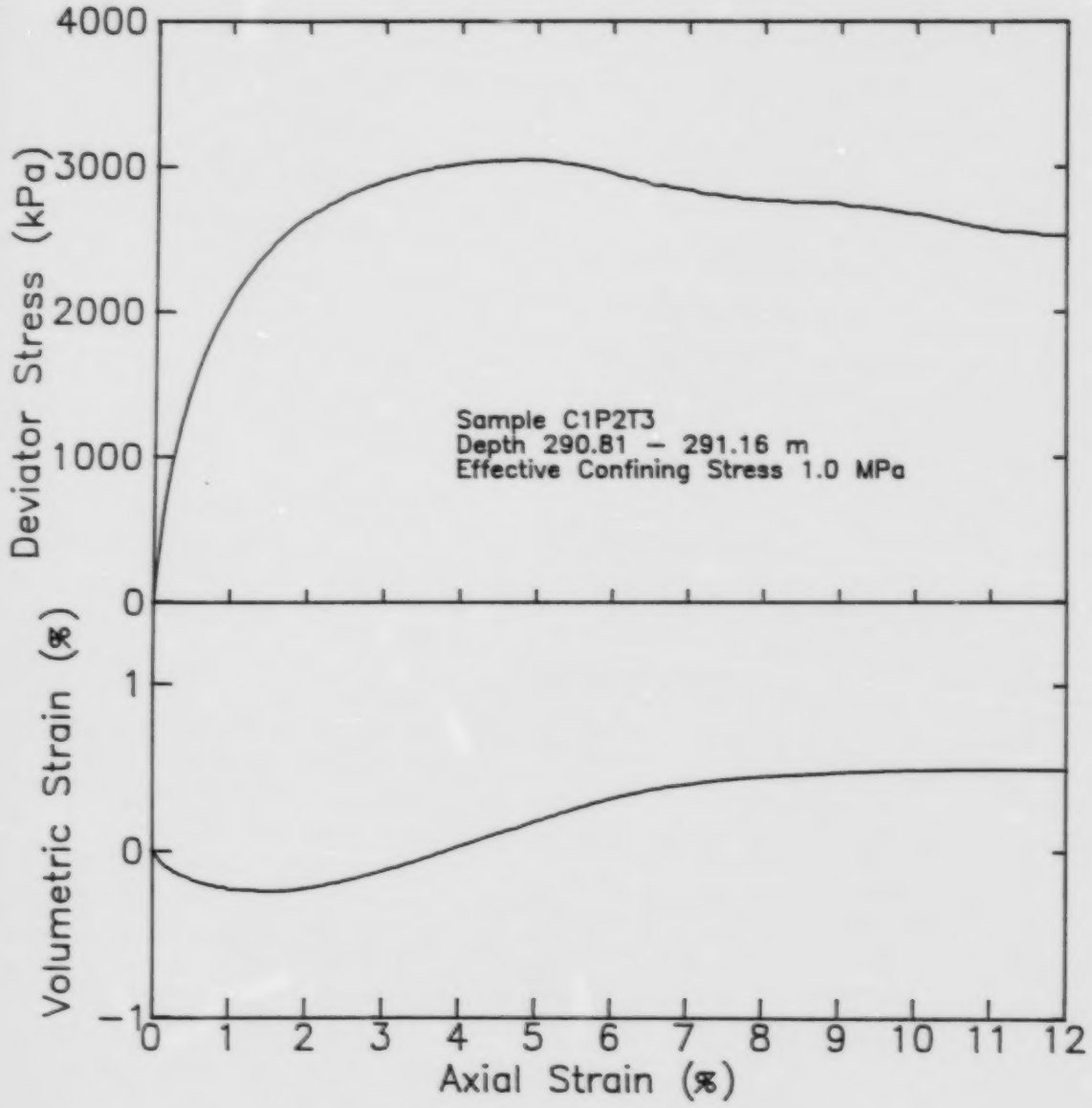
Figure 4



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C3P2T3

DEPTH: 328.20 - 328.61 m

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Medium rich oil sand, no shale bands, infrequent cracks (post lathing disturbance?) sisshapen sample.

TYPE OF TEST: Task 3

DATE TEST COMPLETED: 13 July 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 kPa above in situ confining stress (3104 + 1000 kPa).

07 Reduce radial effective stress to 1 kPa below in situ confining stress (3104 - 1000 kPa) allowing consolidation.

010 Perform 3 cycles of passive drained compression.

REMARKS: oil 9.1% water 3.5% solid 87.4% (by mass)

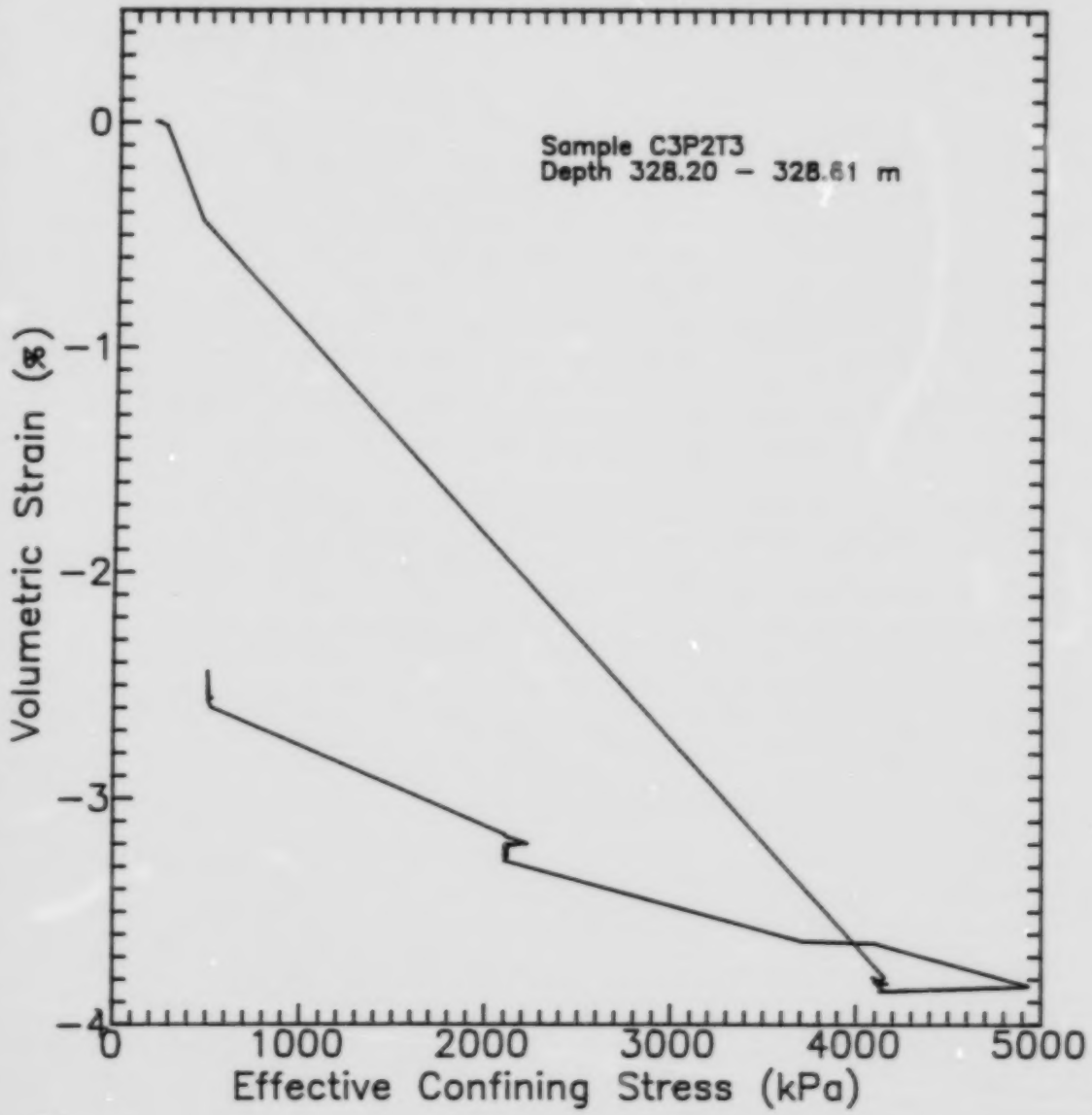
porosity before testing 40.1%

porosity in situ 27.6%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 45.3%

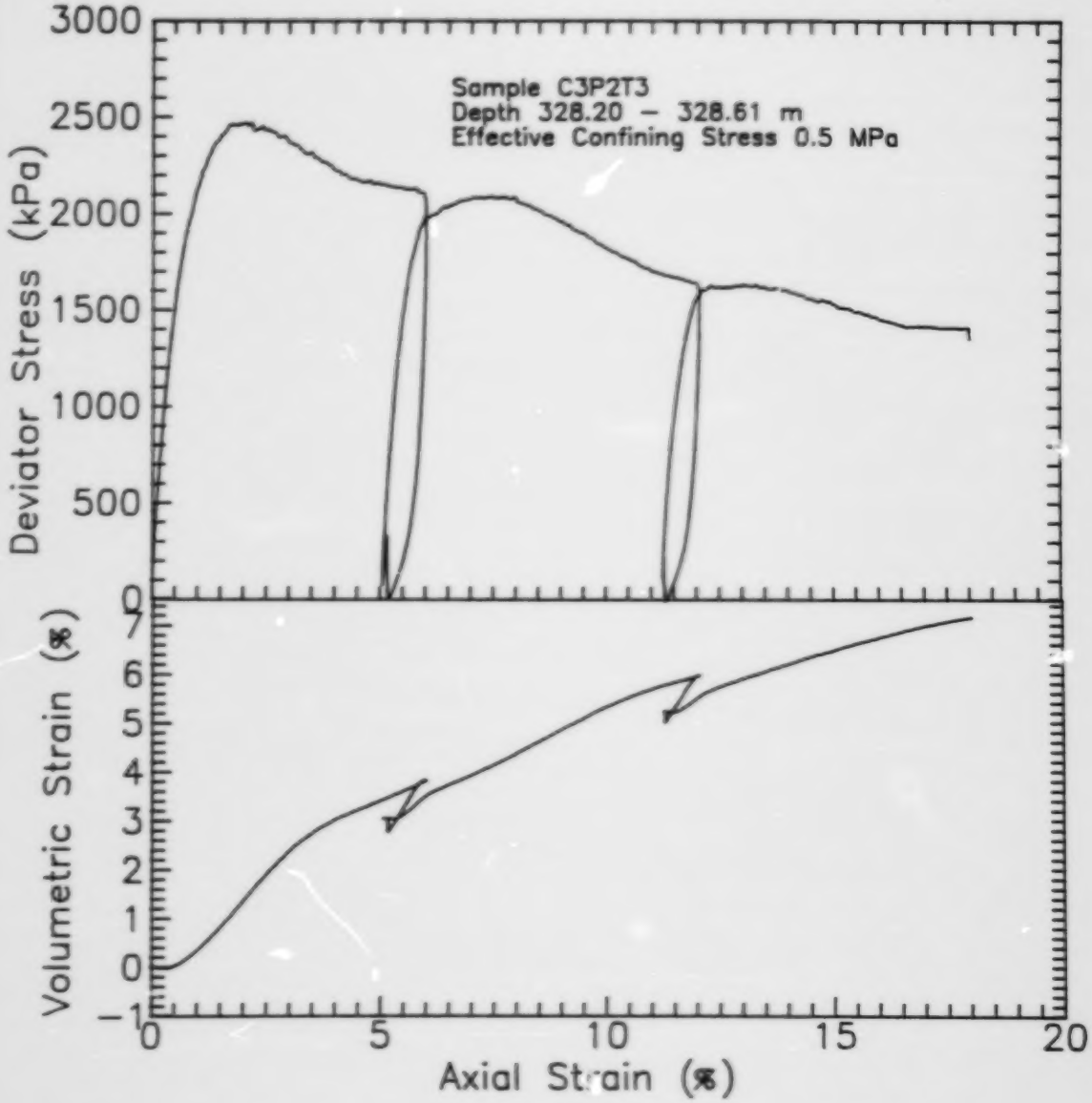
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ___B1P7T3B_____

DEPTH: ___300.46 - 300.82_____

GEOLOGICAL UNIT: __Upper Sand_____

VISUAL DESCRIPTION: Rich Oil Sand_____

TYPE OF TEST: __Test 3_K0>1_____

DATE TEST COMPLETED: _13 June 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _04 and 05____Effective confining stress = 200 kPa_____

_06_Isotropic consolidation at 1 aPa above in situ confining____

____stress (3300 + 1000 kPa)._____

_010 Perform active drained extension test._____

REMARKS: __oil 15.0%_water 1.8%_solid_83.2%_(by mass)_____

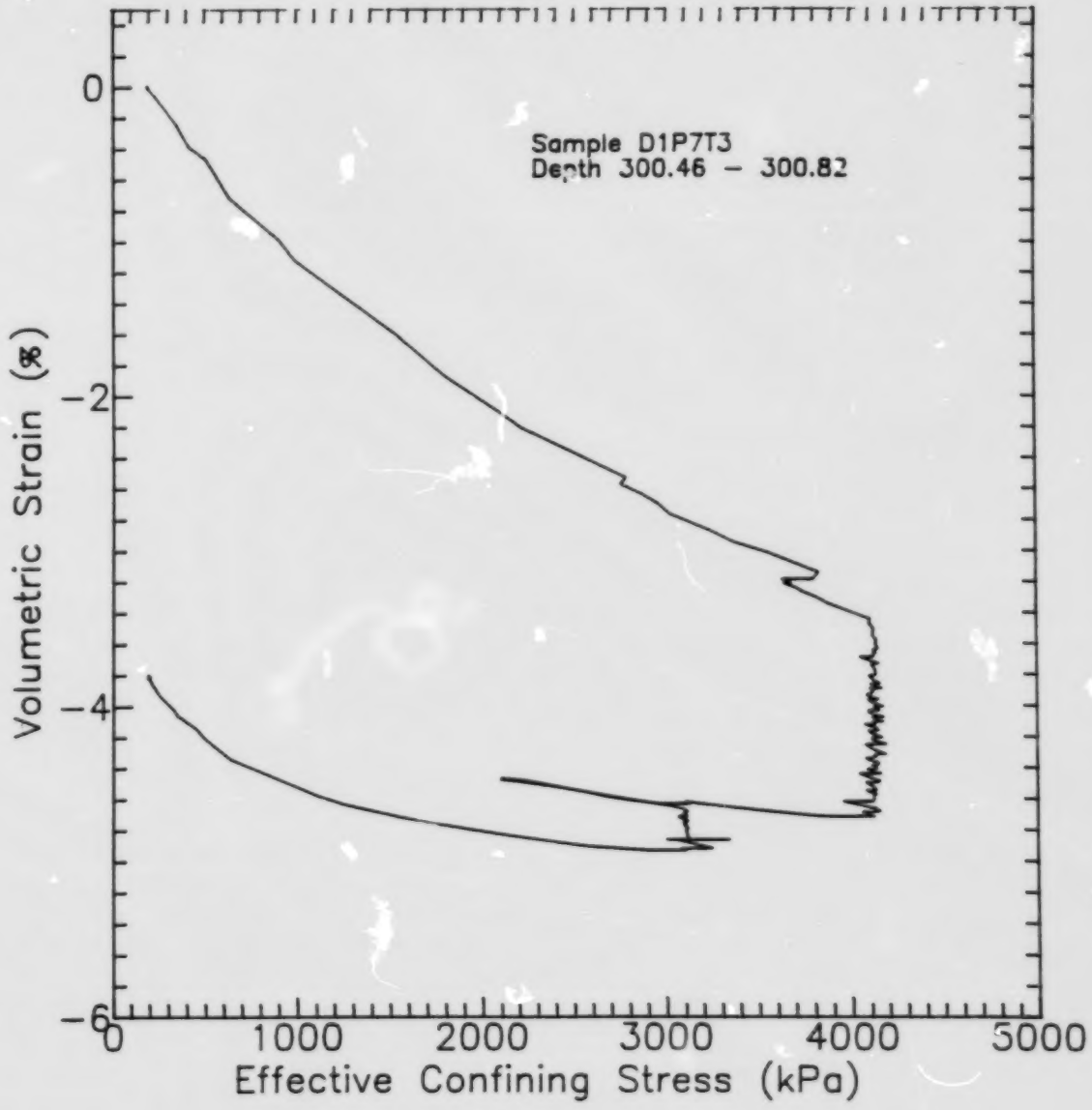
__porosity before testing 46.7%_____

__porosity in situ 34.8%_____

__Index of Disturbance 34.1%_____

__(porosity is defined as ratio of void volume to total volume)_____

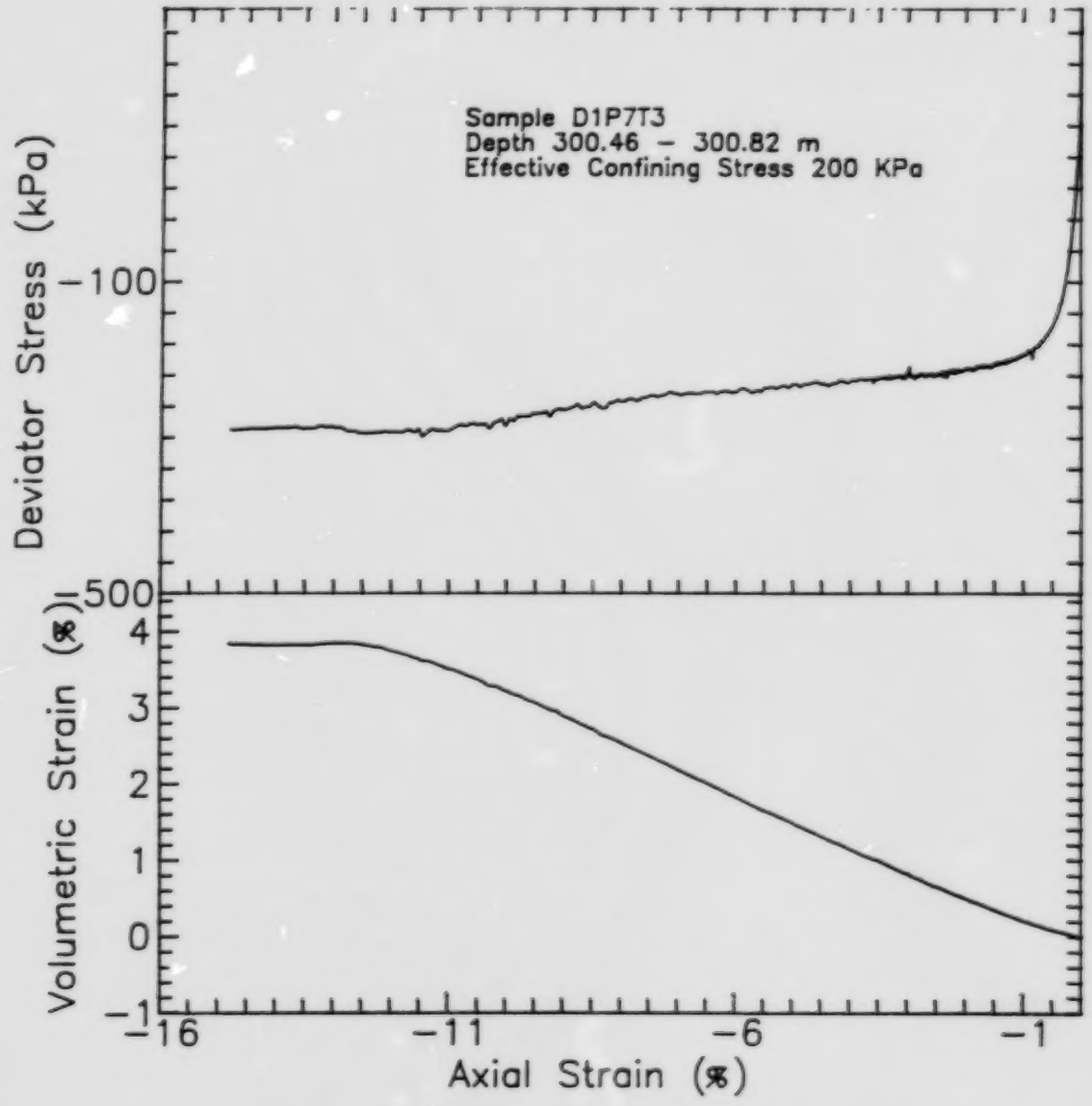
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT NO. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: DIP7

DEPTH: 300.46 - 300.82

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand, Some visible cracking on sample

TYPE OF TEST: Task 3

DATE TEST COMPLETED: 4 June 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 mPa above in situ confining stress (3104 + 1000 kPa).

REMARKS: oil 15.0% water 1.8% solid 83.2% (by mass)

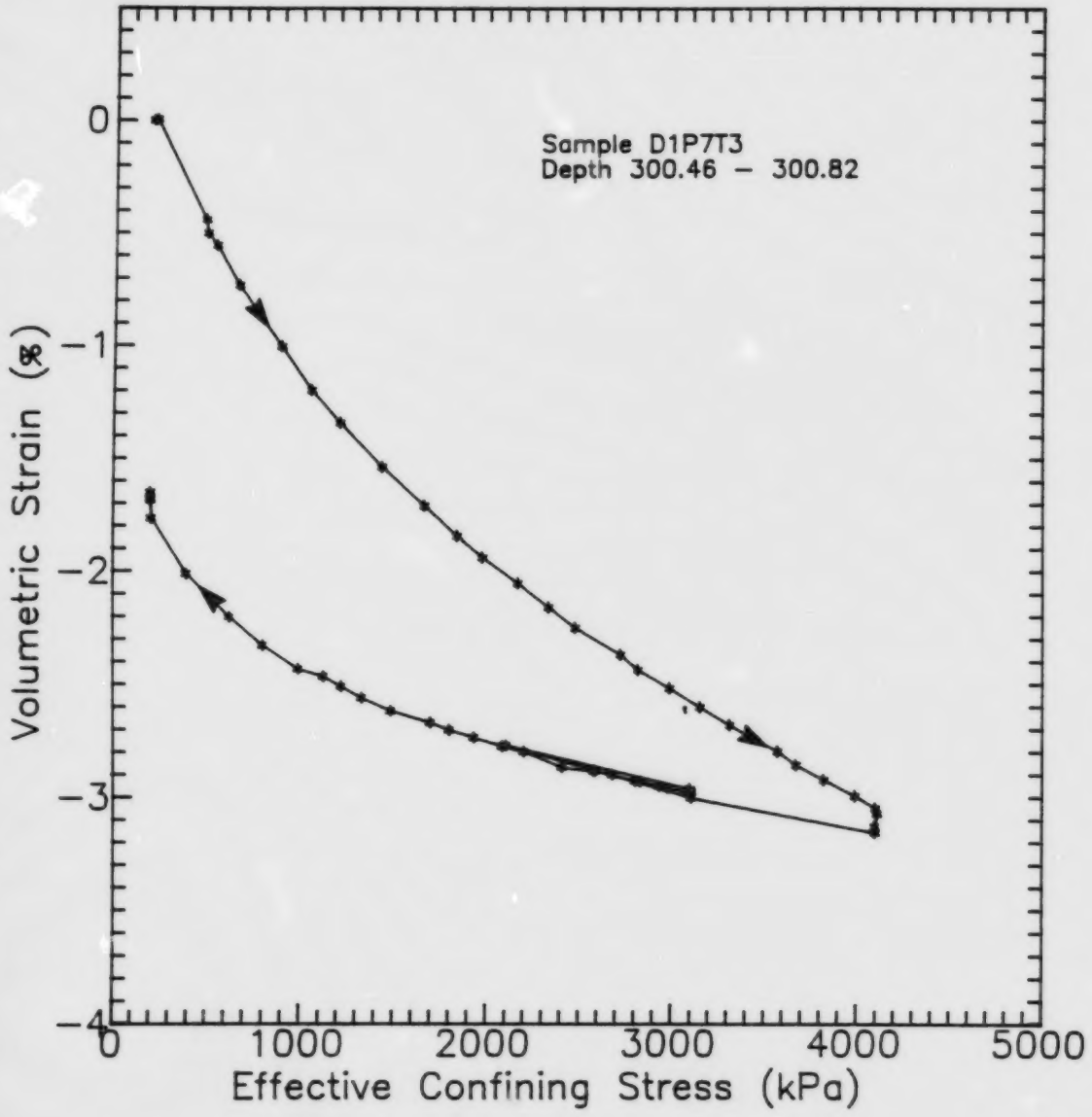
porosity before testing 47.5%

porosity in situ 34.8%

Index of Disturbance 36.4%

(porosity is defined as ratio of void volume to total volume)

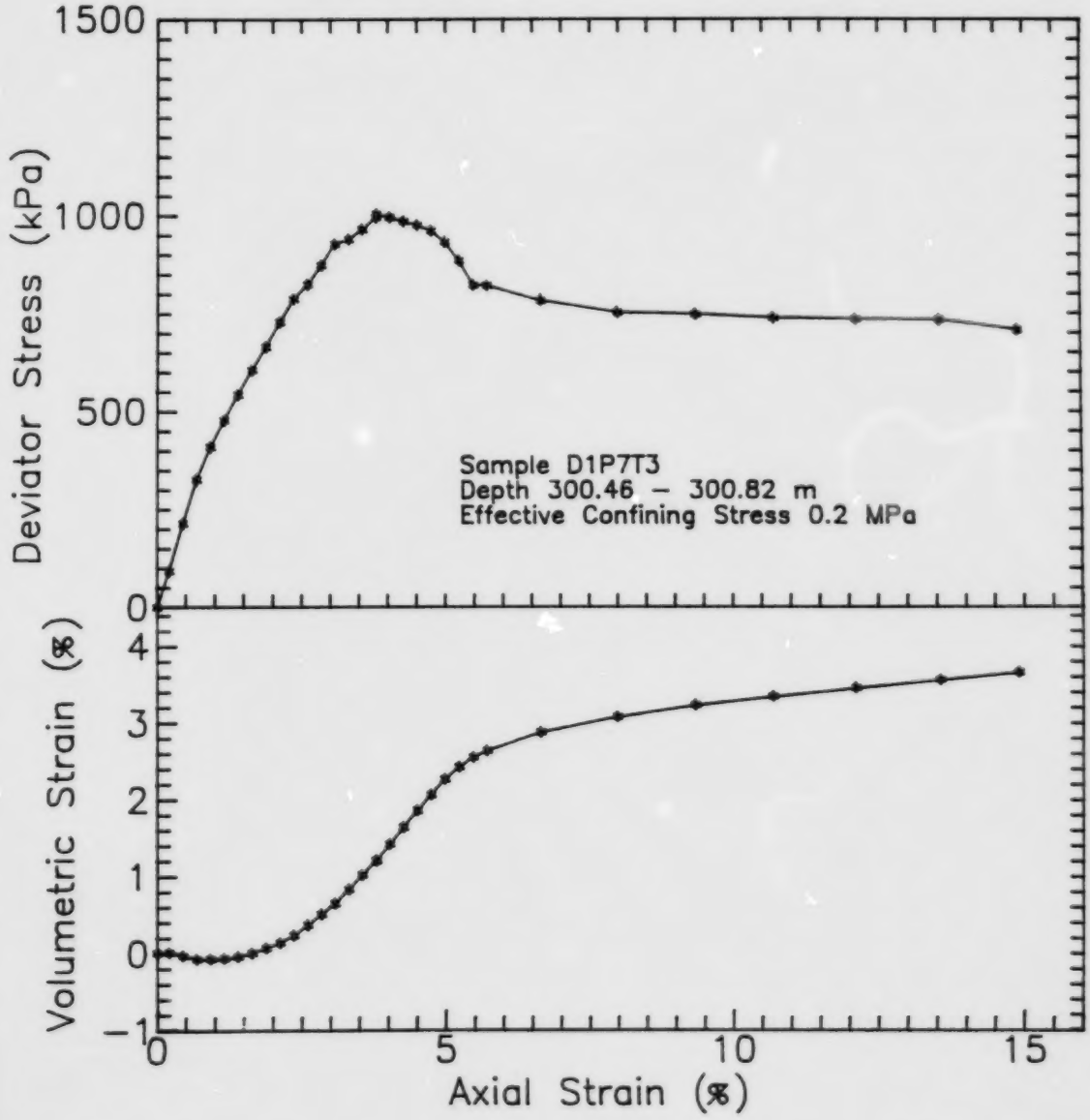
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

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CONSULTING ENGINEERS

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LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ____B1P7T3C_____

DEPTH: ____300.46 - 300.82_____

GEOLOGICAL UNIT: __Upper Sand_____

VISUAL DESCRIPTION: _Rich oil sand, cracking visible, significant disturbance._____
Sample consolidated in cell then removed due to slow membrane leak, and refrozen under
_confining stress._____

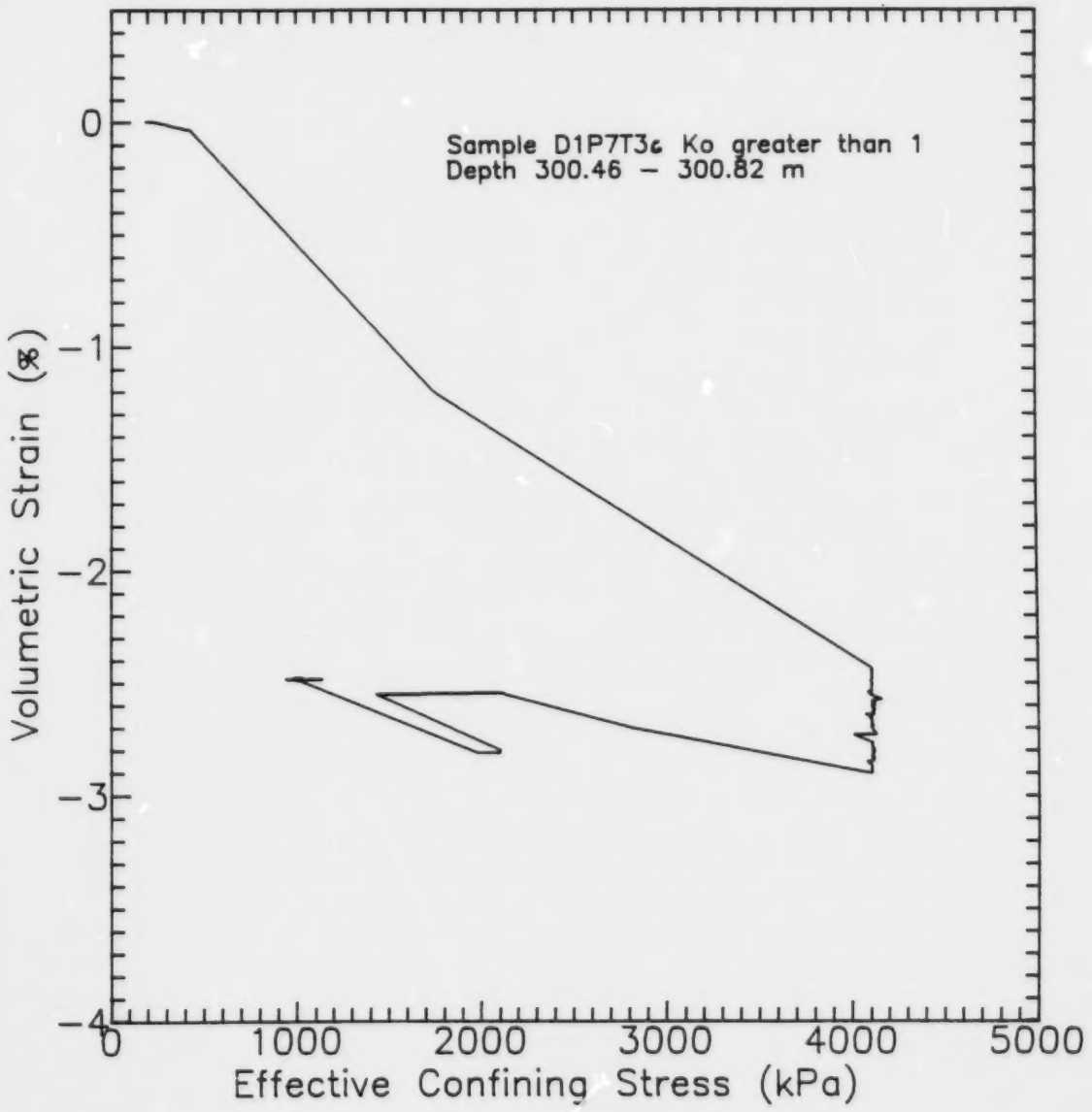
TYPE OF TEST: __Task 3_____

DATE TEST COMPLETED: _6 July 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _04 and 05____Effective confining stress = 200 kPa_____
_06__Isotropic consolidation at 1 mPa above in situ confining____
____stress (3104 + 1000 kPa)._____
_07__Reduce radial effective stress to 1 mPa below in situ_____
____confining stress (3104 - 1000 kPa) allowing consolidation.__
_010__Increase radial stress while maintaining constant axial ___
_____stress (1000 kPa)._____

REMARKS: __oil 15.0%_water 1.8%_solid_83.2%_(by mass)_____
__porosity before testing 38.7%_____
__porosity in situ 34.8%_____
__(porosity is defined as ratio of void volume to total volume)_____
__index of disturbance 11.1%_____
_____
_____

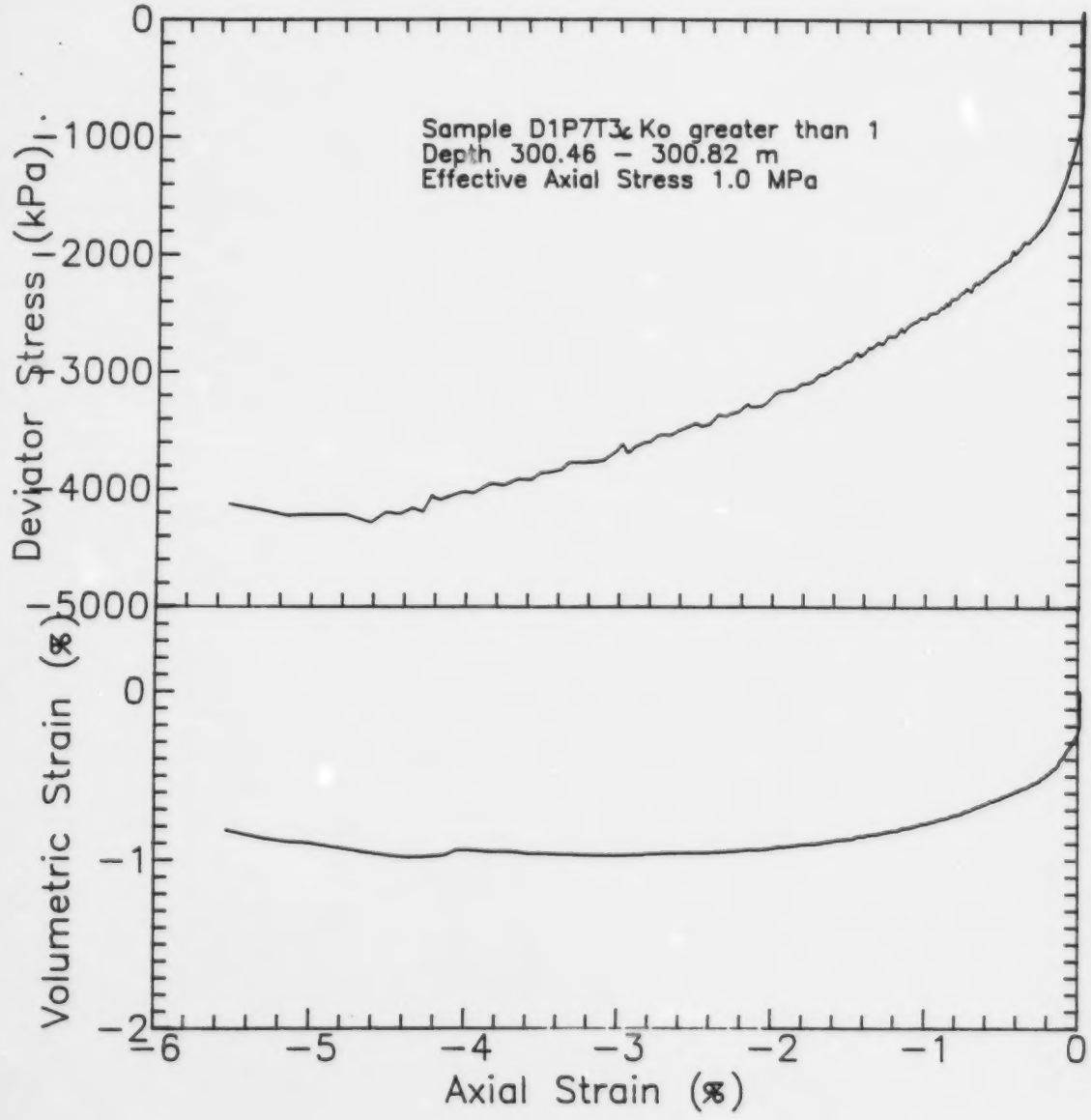
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Extension Test
Ko greater than 1

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D2P4T38

DEPTH: 305.54 - 305.87

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

Cracking on sample

TYPE OF TEST: Task 3 KO>1

DATE TEST COMPLETED: 14 June 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 mPa above in situ confining stress (3104 + 1000 kPa).

010 Perform active drained extension test.

REMARKS: oil 15.3% water 1.2% solid 83.3% (by mass)

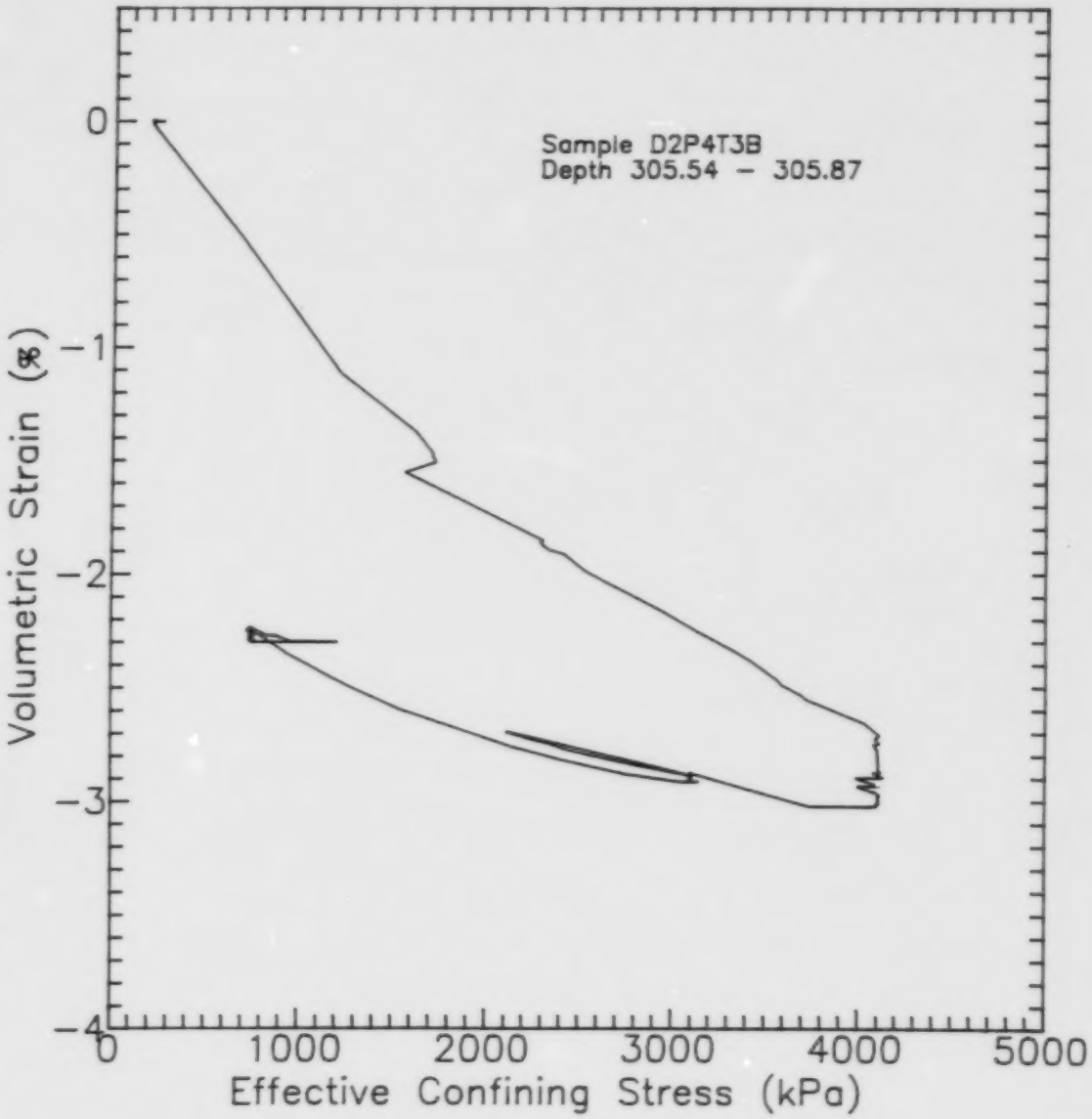
porosity before testing 45.4%

porosity in situ 34.6%

Index of Disturbance 31.1%

(porosity is defined as ratio of void volume to total volume)

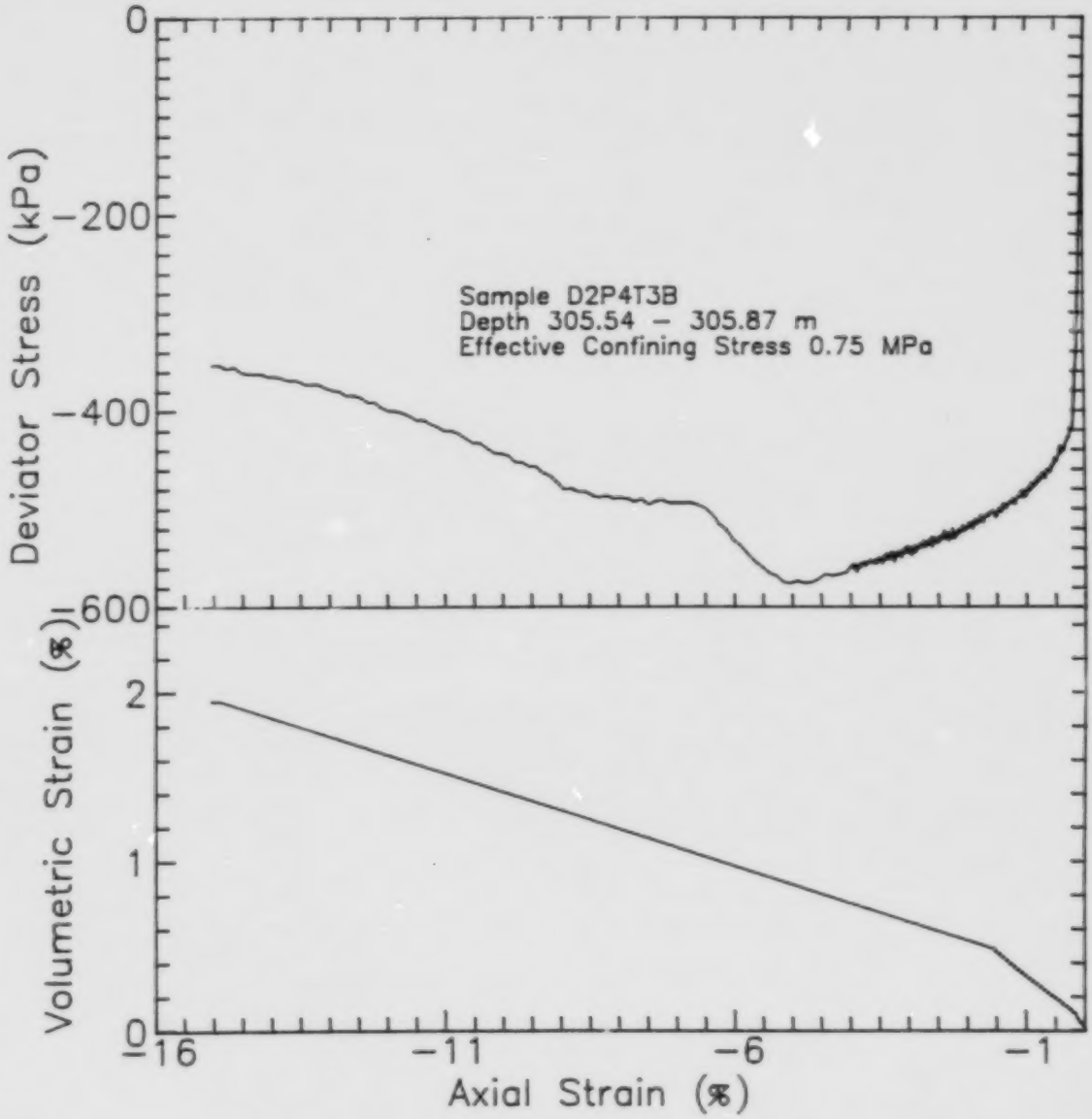
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D2P4

DEPTH: 305.54 - 305.87

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 3

DATE TEST COMPLETED: 5 June 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 aPa above in situ confining stress (3104 + 1000 kPa).

REMARKS: oil 15.5% water 1.2% solid 83.3% (by mass)

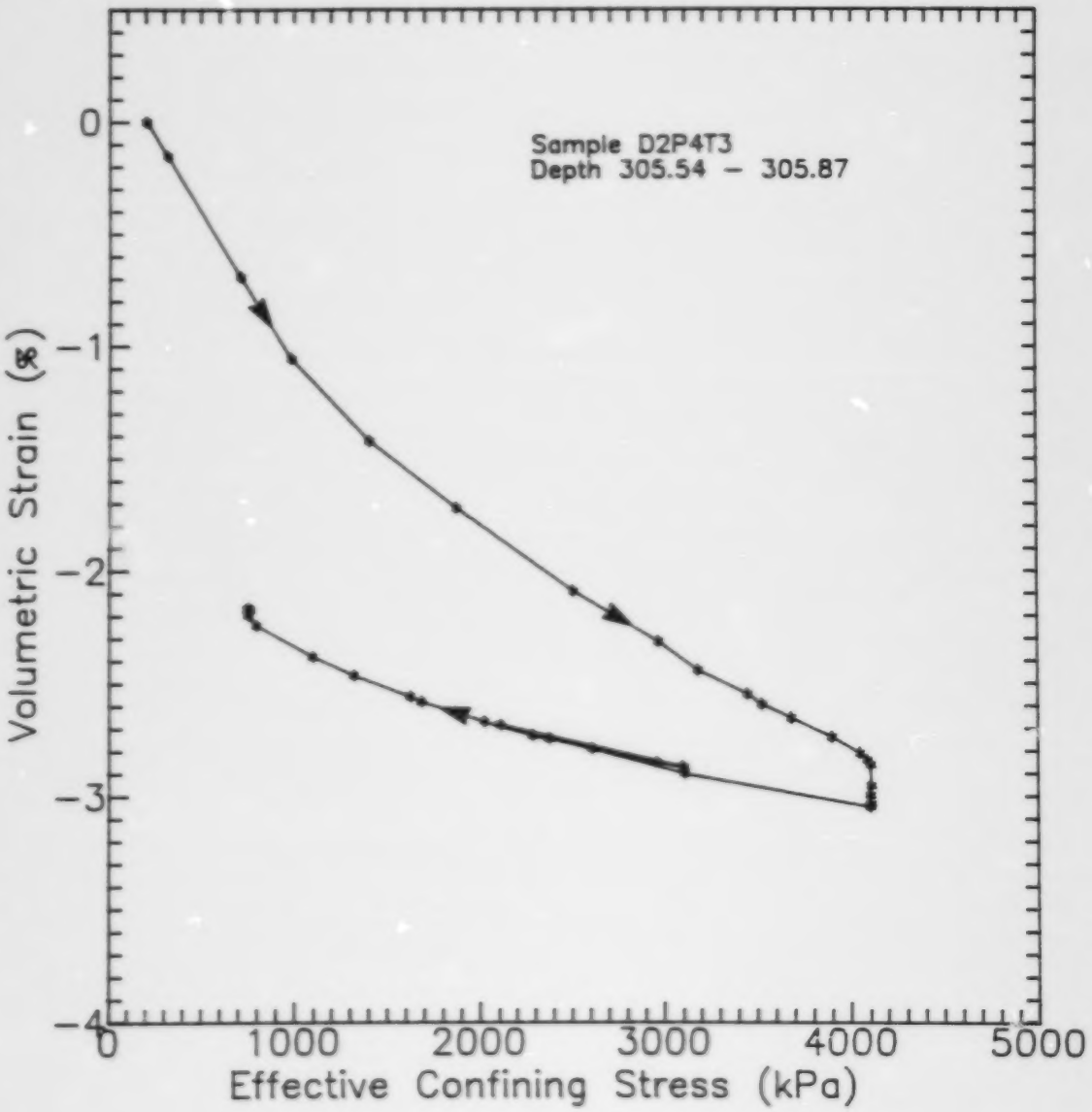
porosity before testing 46.0%

porosity in situ 34.6%

Index of Disturbance 32.8%

(porosity is defined as ratio of void volume to total volume)

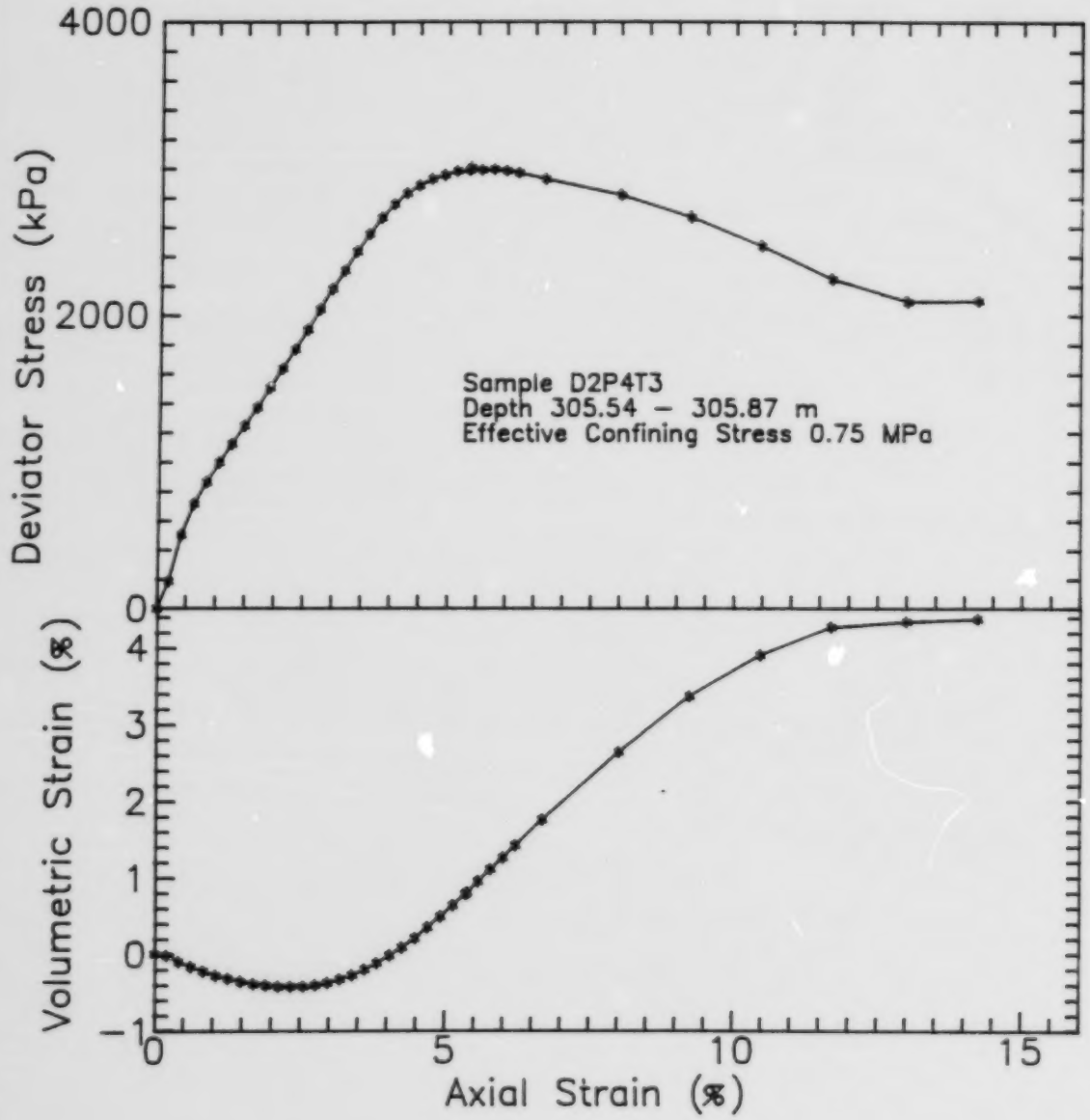
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: 02P4T3C

DEPTH: 305.54 - 305.87

GEOLOGICAL UNIT: Upper Sand

VISUAL DESCRIPTION: Much disturbance, cracks

TYPE OF TEST: Task 3 Ko > 1

DATE TEST COMPLETED: 12 July 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 mPa above in situ confining stress (3104 + 1000 kPa).

07 Reduce radial effective stress to 1 MPa below in situ confining stress (3104 - 1000 kPa) allowing consolidation.

010 Increase radial stress while maintaining constant axial stress (500 kPa).

REMARKS: oil 15.5% water 1.2% solid 83.3% (by mass)

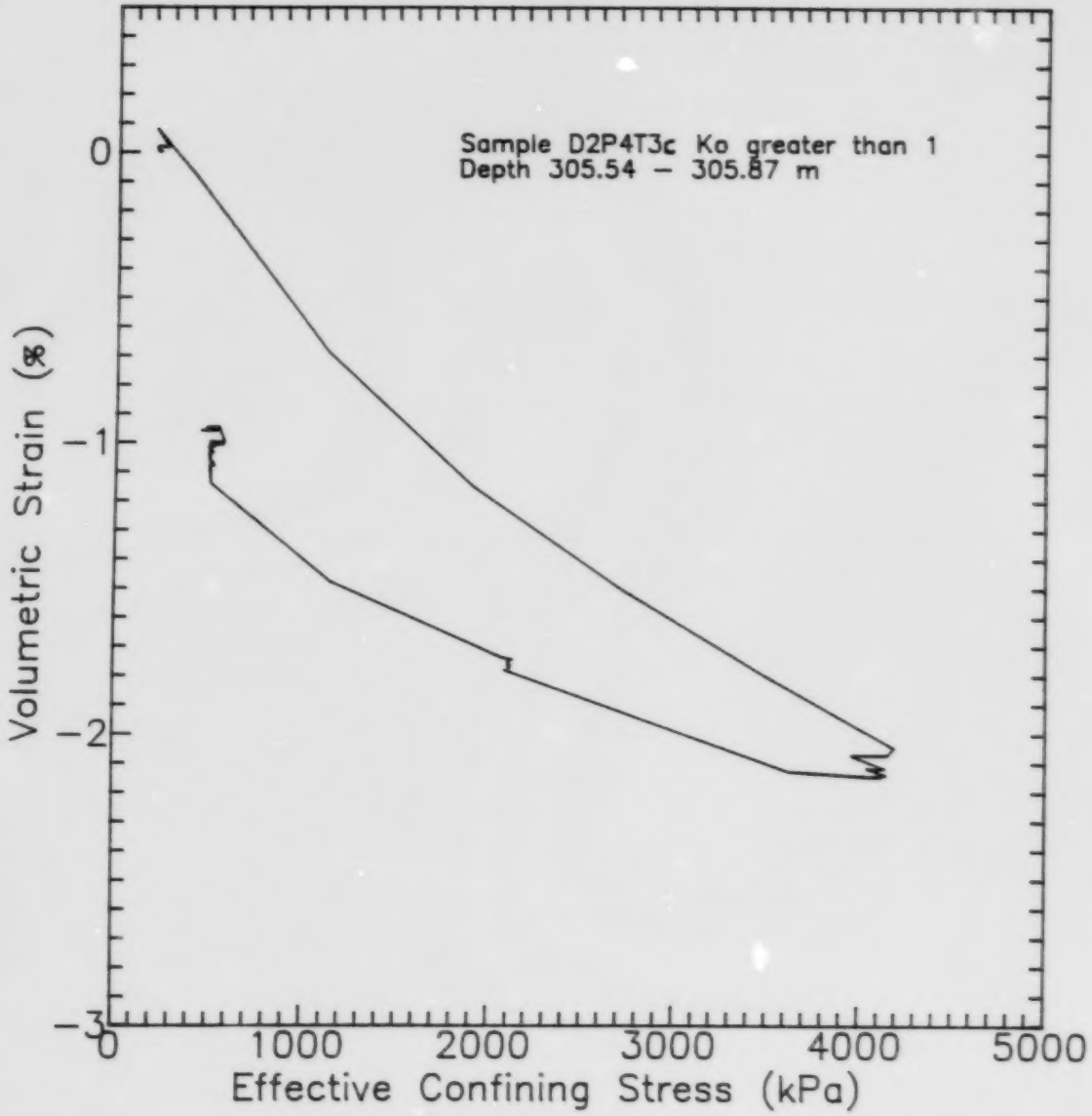
porosity before testing 44.5%

porosity in situ 34.6%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 28.6%

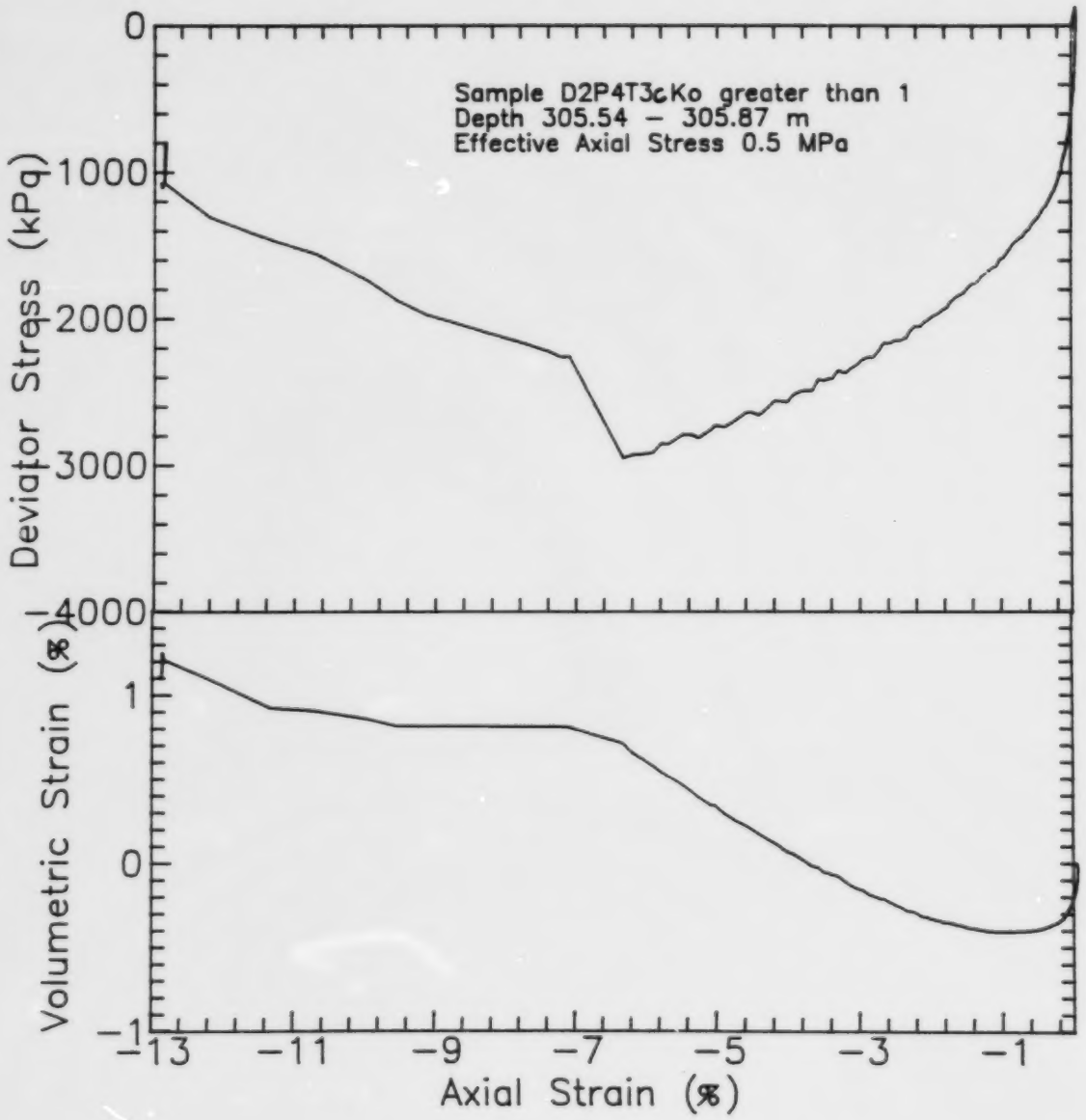
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Extension Test
Ko greater than 1

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ____B2P3T3_____

DEPTH: ____308.47 - 308.82_____

GEOLOGICAL UNIT: __Lover Sand_____

VISUAL DESCRIPTION: _Rich Oil Sand_____

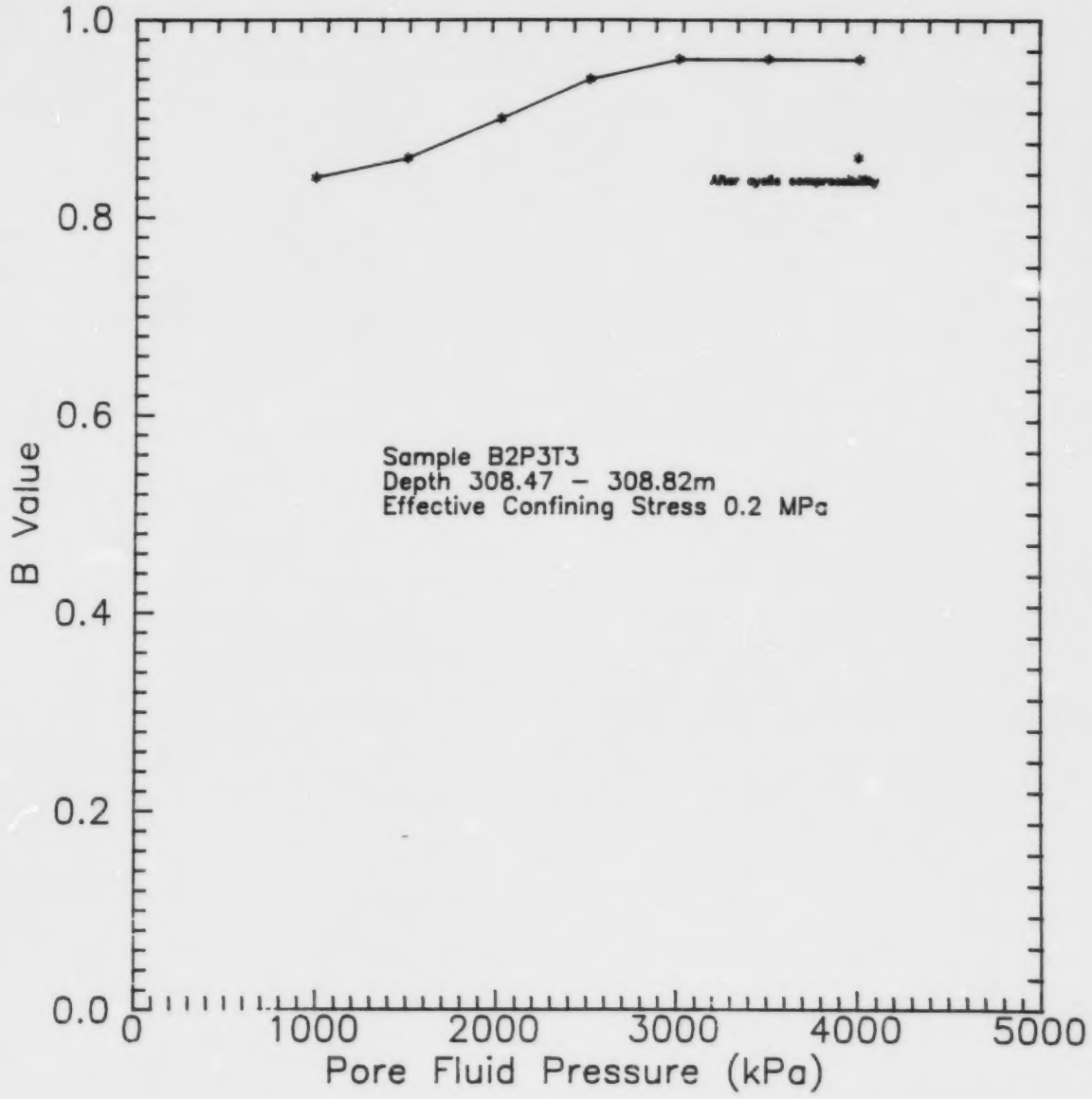
TYPE OF TEST: __Task 3_____

DATE TEST COMPLETED: _11 April 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _#4 and #5____Effective confining stress = 200 kPa_____

REMARKS: _____

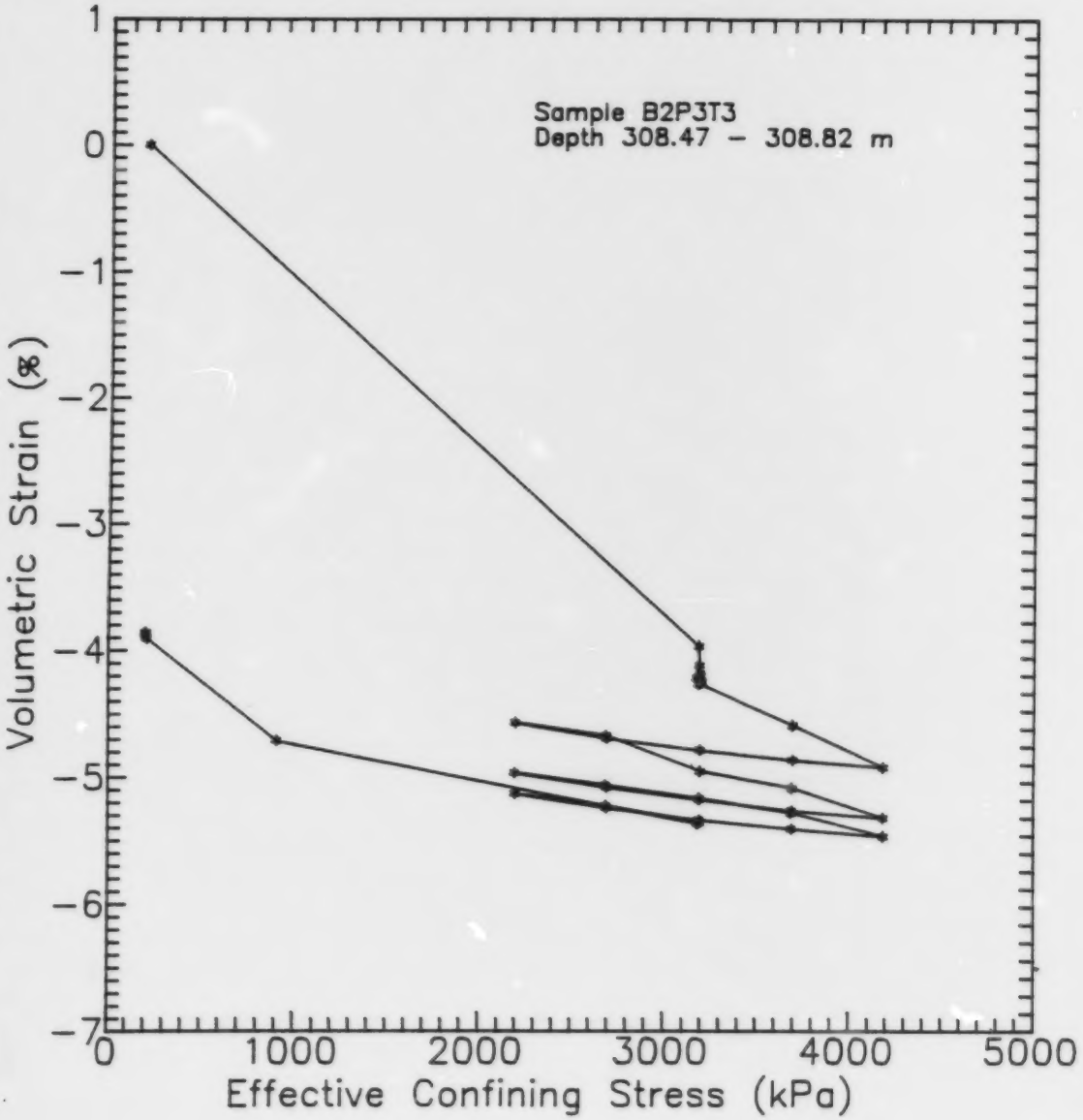
Figure



Task 3 – Pore pressure Parameter B Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

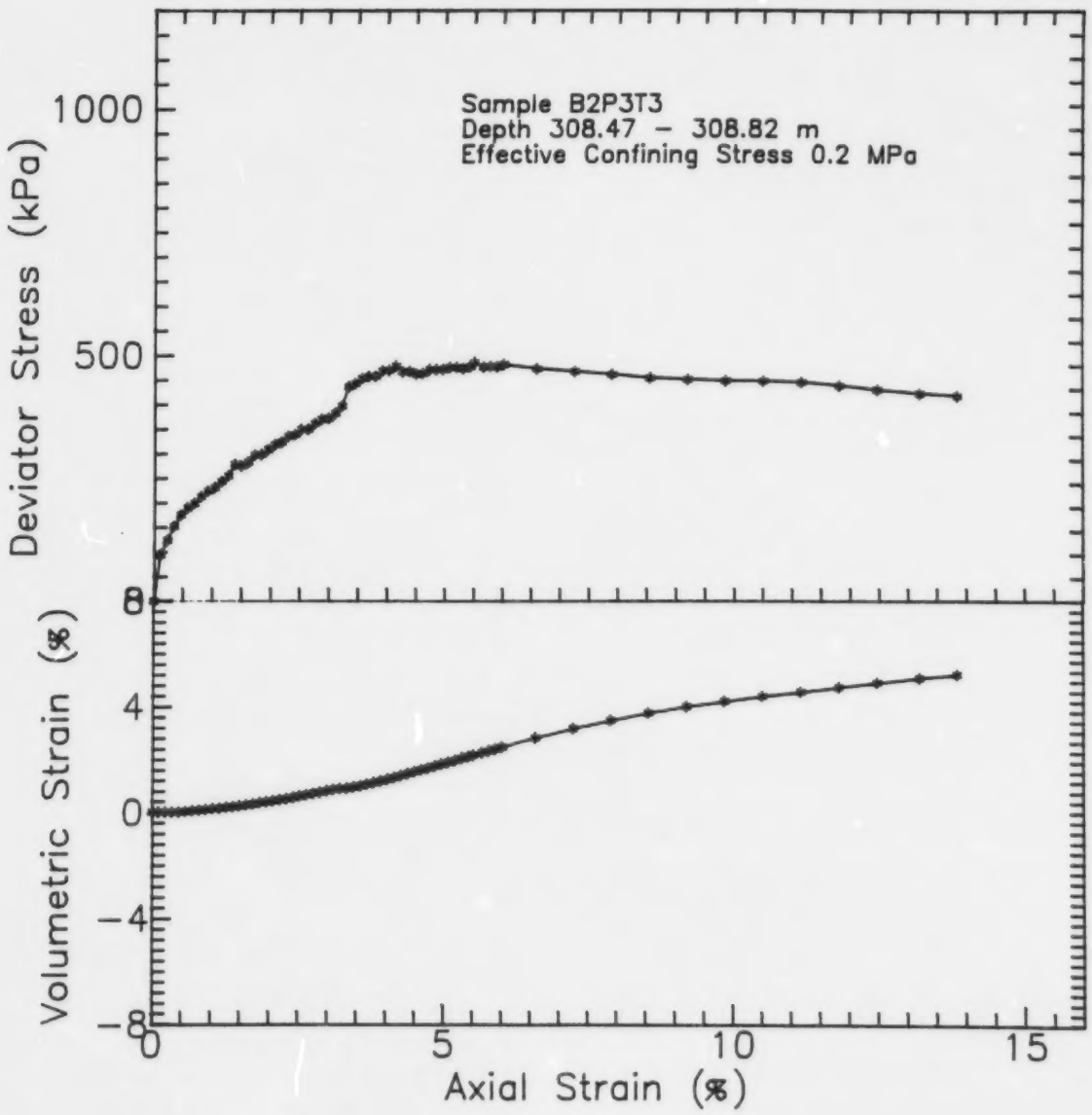
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ____B2P1T3_____

DEPTH: ____296.86 - 297.22_____

GEOLOGICAL UNIT: __Upper Sand_____

VISUAL DESCRIPTION: _Rich Oil Sand_____

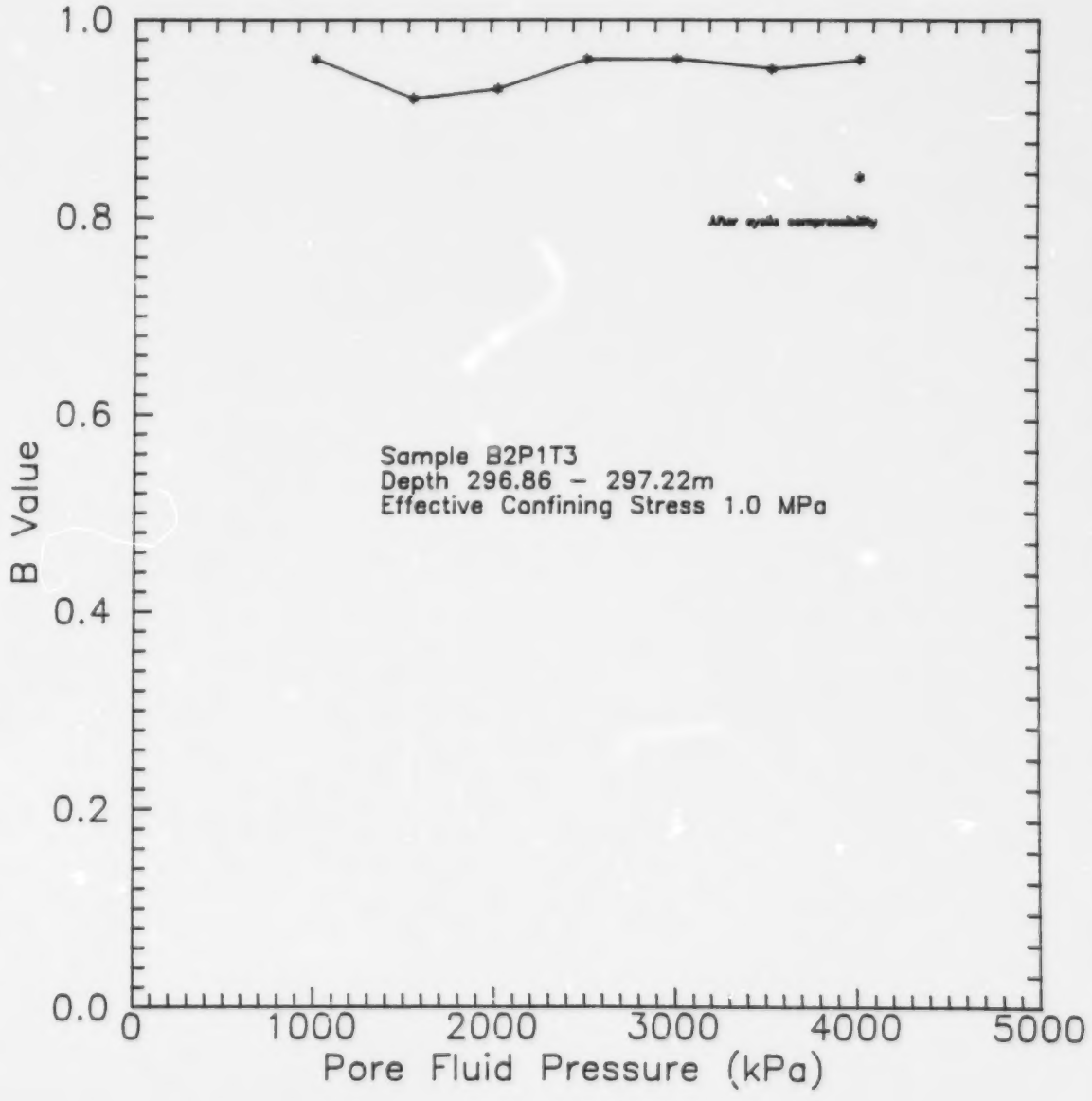
TYPE OF TEST: __Task 3_____

DATE TEST COMPLETED: _16 April 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _#4 and #5____Effective confining stress = 200 kPa_____

REMARKS: _____

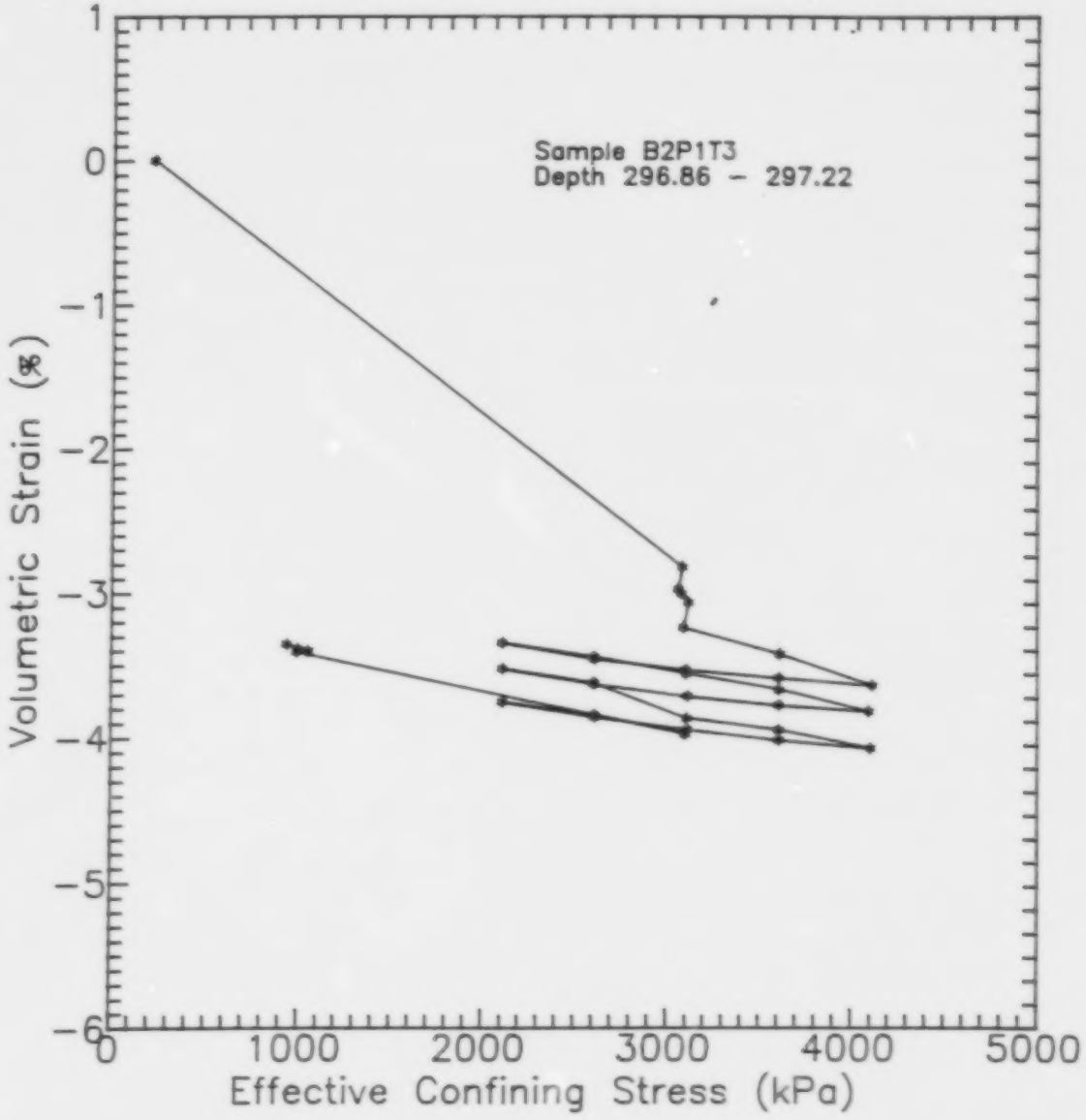
Figure X



Task 3 – Pore pressure Parameter B Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

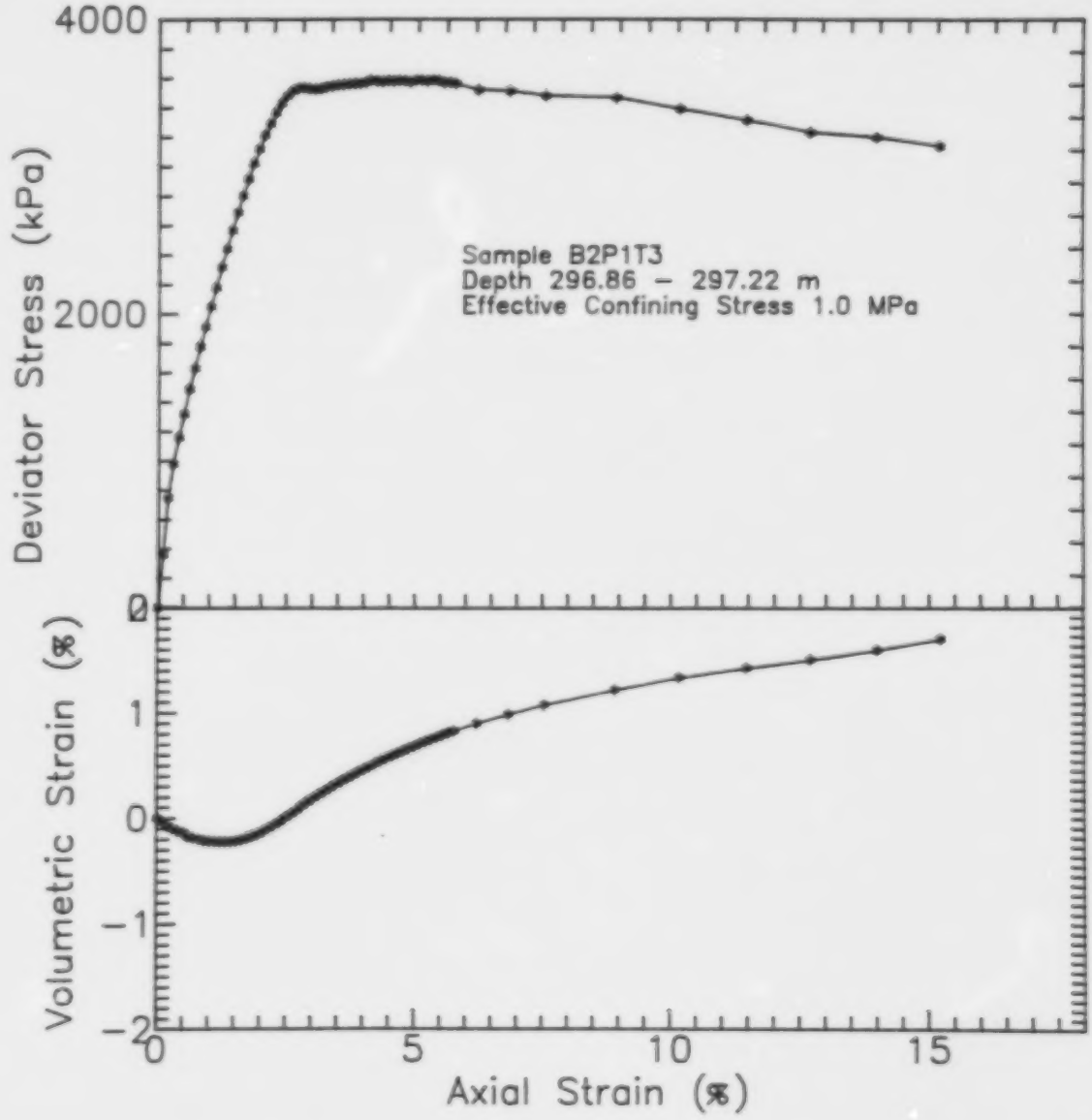
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

692-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D2P8T3T

DEPTH: 327.82 - 328.21 m

GEOLOGICAL UNIT: Laminar

VISUAL DESCRIPTION: Rich oil sand, very nice sample, well shaped, slight disturbance only

TYPE OF TEST: Task 3 at 100 degrees Celcius

DATE TEST COMPLETED: 13 August 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 aPa above in situ confining stress (3300 + 1000 kPa).

07 Reduce radial effective stress to 1 aPa below in situ confining stress (3300 - 1000 kPa) allowing consolidation.

010 Heat sample to 100 degrees Celcius and perform passive drained compression test while maintaining temperature.

REMARKS: oil 16.6% water 3.3% solid 80.1% (by mass)

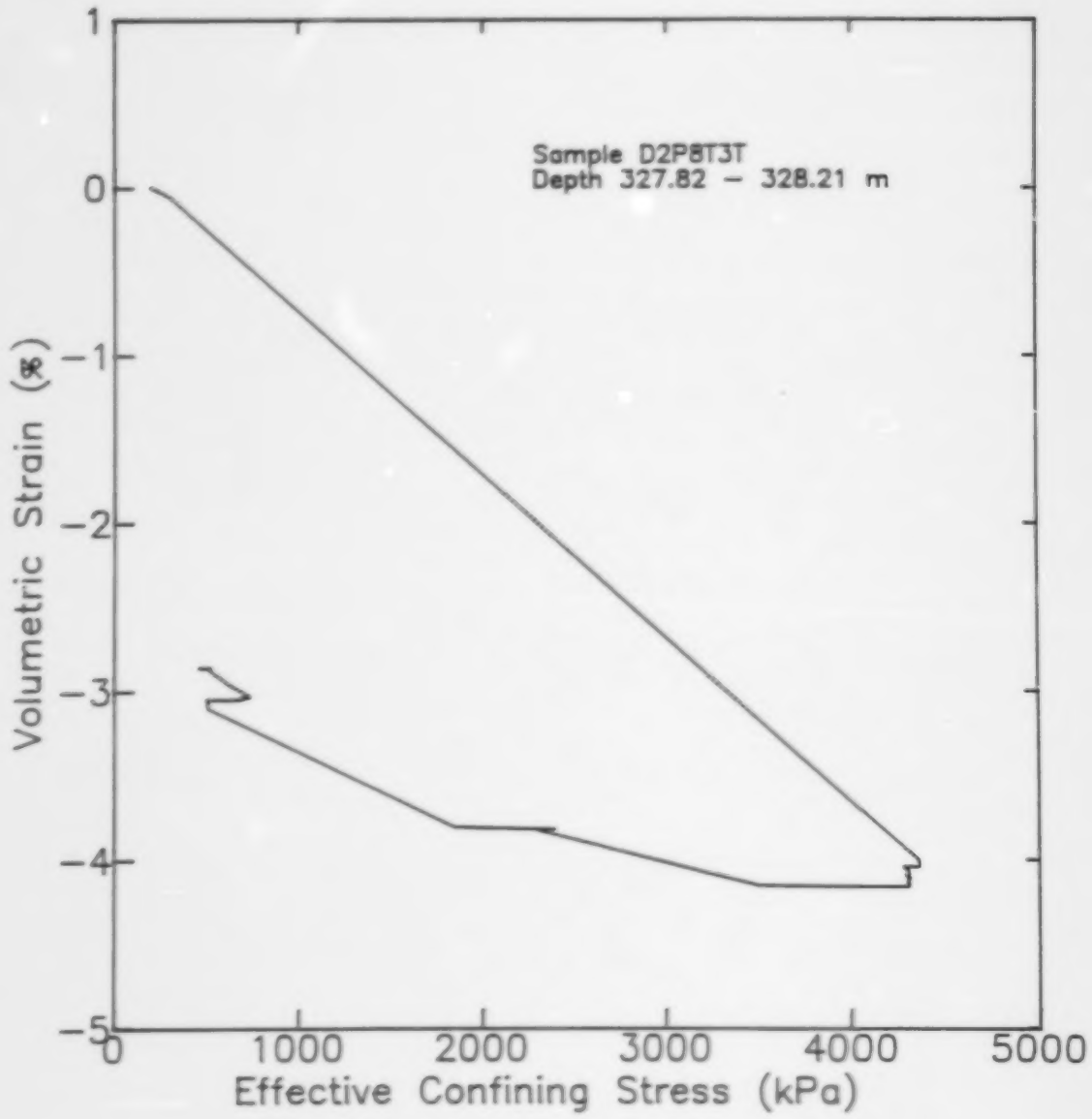
porosity before testing 46.2%

porosity in situ 39.6%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 16.4%

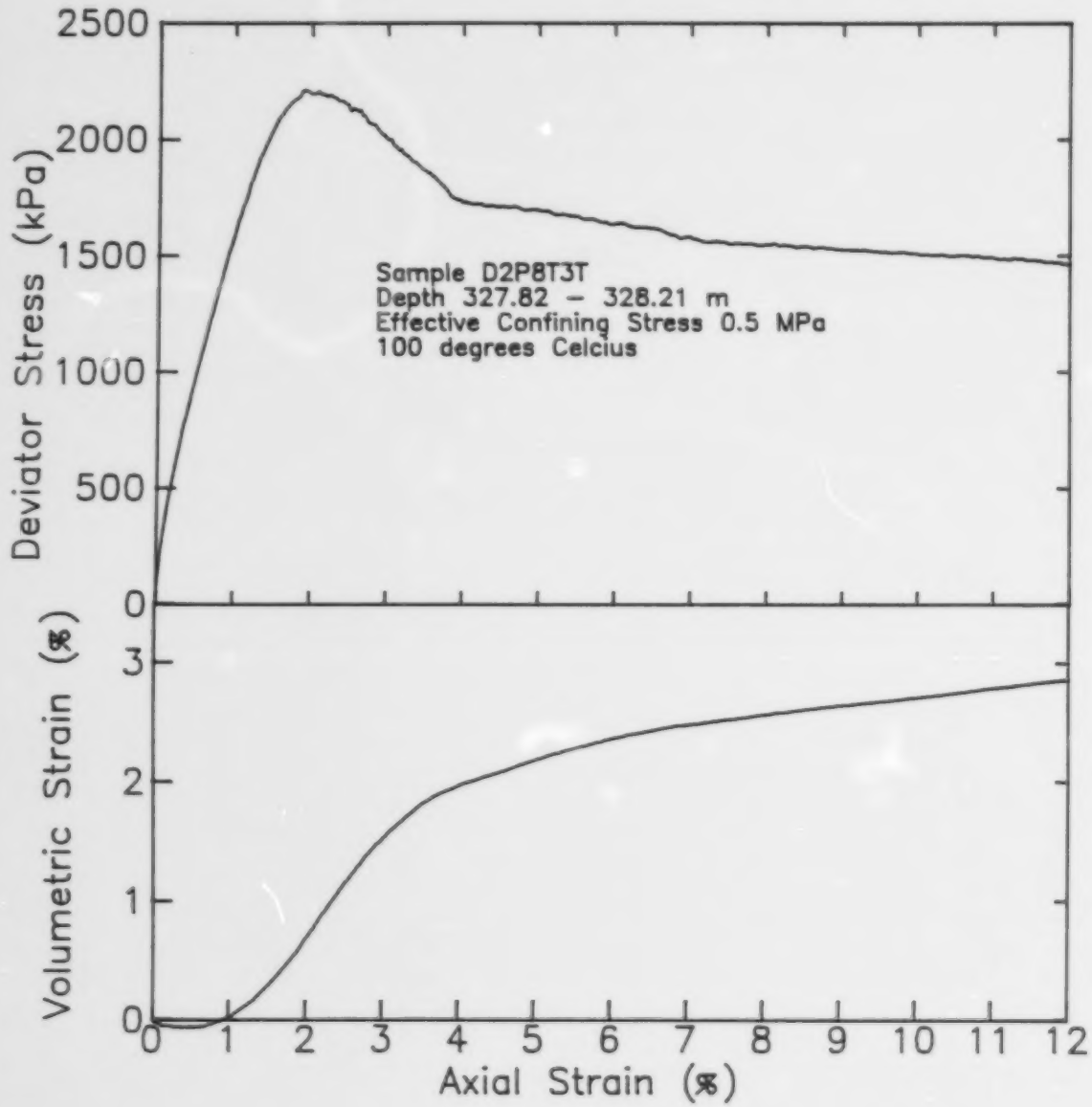
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D2P8T38

DEPTH: 327.82 - 328.21

GEOLOGICAL UNIT: Laminar

VISUAL DESCRIPTION: Rich Oil Sand

TYPE OF TEST: Task 3

DATE TEST COMPLETED: 11 June 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 mPa above in situ confining stress (3300 + 1000 kPa).

REMARKS: oil 16.6% water 3.3% solid 80.1% (by mass)

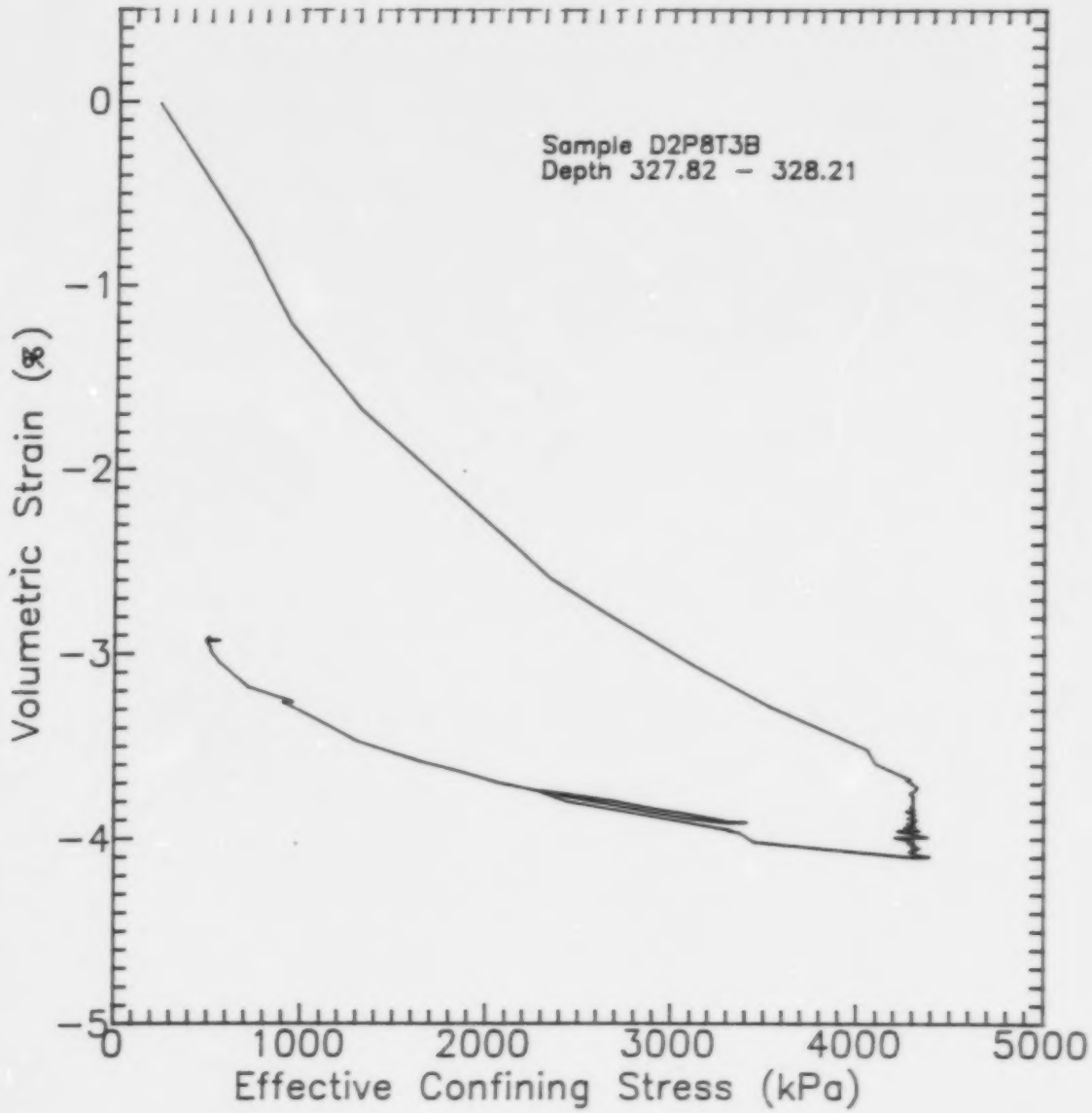
porosity before testing 47.2%

porosity in situ 39.6%

Index of Disturbance 18.9%

(porosity is defined as ratio of void volume to total volume)

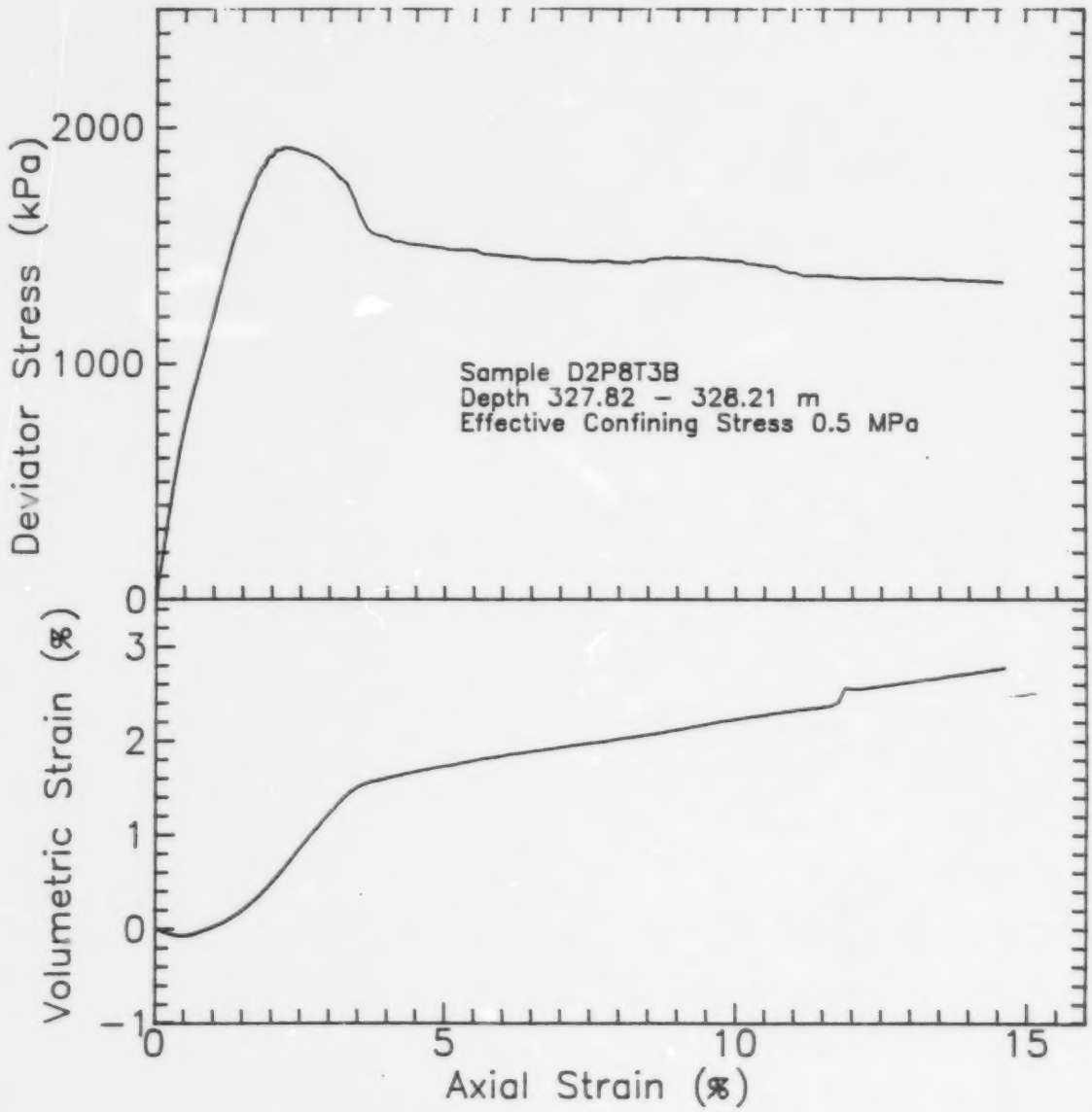
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ____D2P8_____

DEPTH: ____327.82 - 328.21_____

GEOLOGICAL UNIT: __Laminar_____

VISUAL DESCRIPTION: _Rich Oil Sand, slight disturbance on sample_____

TYPE OF TEST: __Task 3_____

DATE TEST COMPLETED: _7 June 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _04 and 05____Effective confining stress = 200 kPa_____

_06__Isotropic consolidation at 1 mPa above in situ confining____

____stress (3300 + 1000 kPa)._____

REMARKS: __oil 16.6%_water 3.3%_solid_80.1%_(by mass)_____

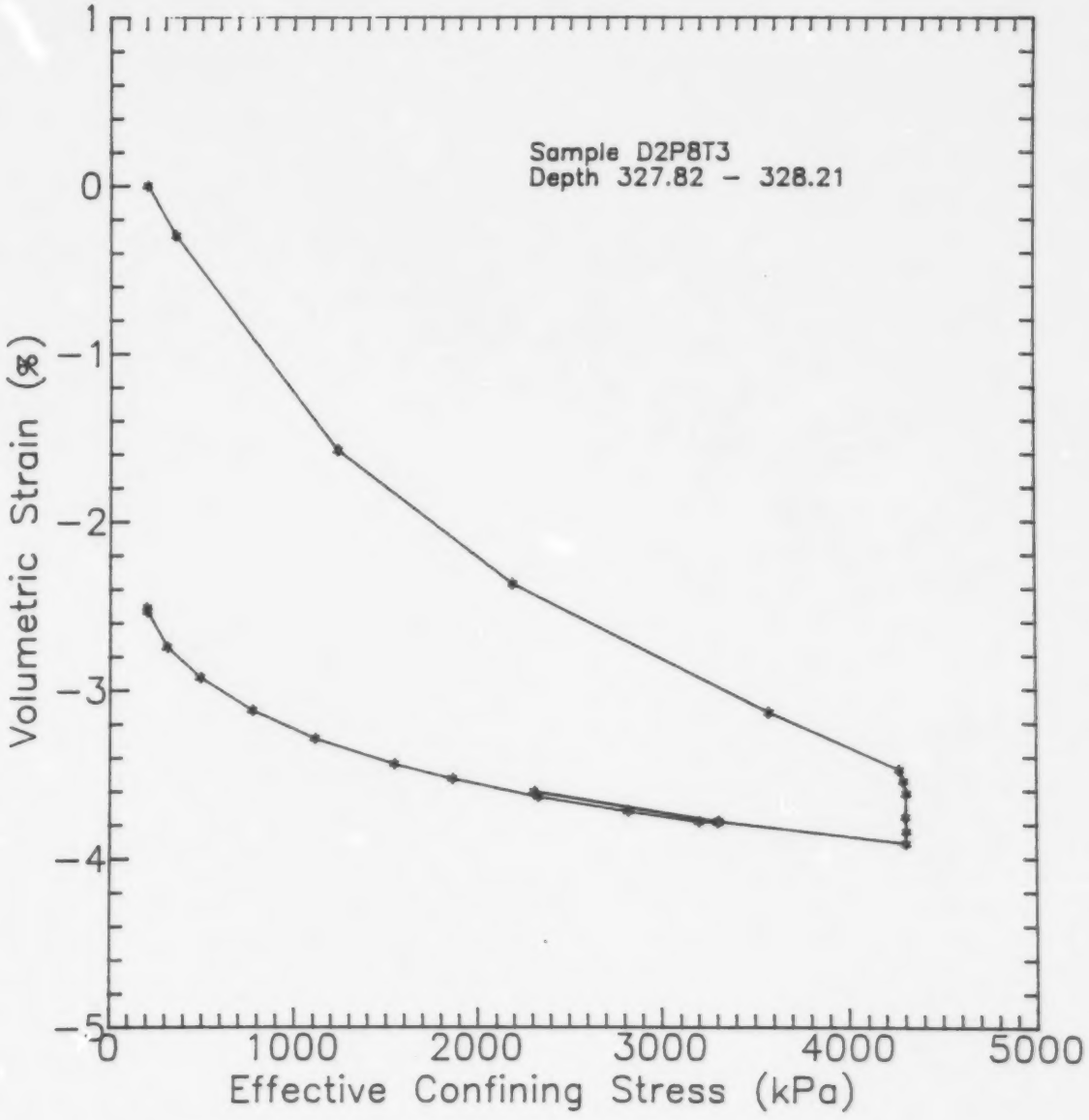
__porosity before testing 47.2%_____

__porosity in situ 39.6%_____

__Index of Disturbance 19.1%_____

__(porosity is defined as ratio of void volume to total volume)_____

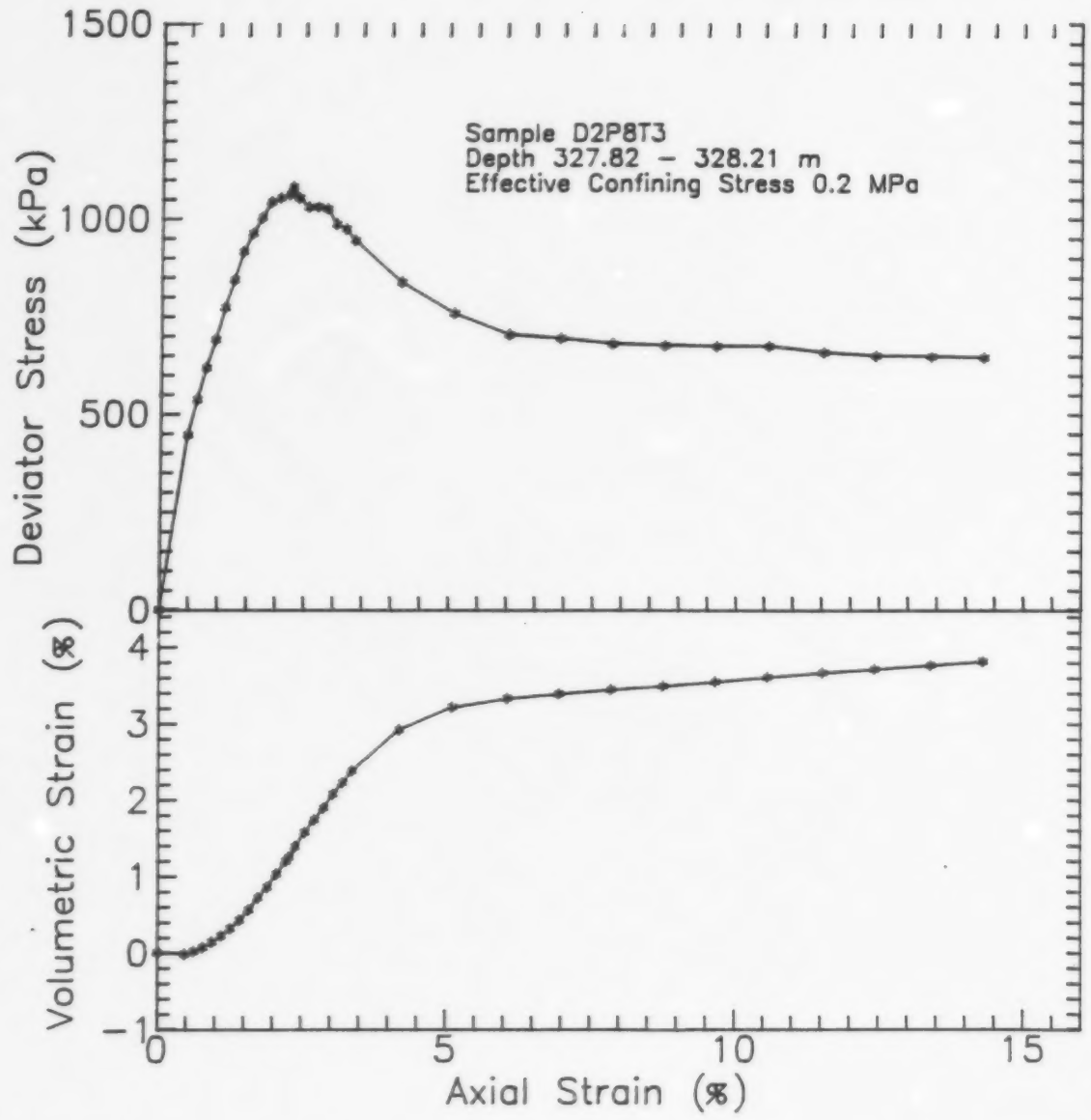
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D1P10T3T

DEPTH: 316.23 - 316.51 m

GEOLOGICAL UNIT: Laminar

VISUAL DESCRIPTION: Medium oil sand, thin shale banding, disturbance, cracking, chipped edges filled with wax at both top and bottom ends.

TYPE OF TEST: Task 3 at 100 degrees Celcius

DATE TEST COMPLETED: 9 August 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #4 and #5 Effective confining stress = 200 kPa

#6 Isotropic consolidation at 1 mPa above in situ confining stress (3300 + 1000 kPa).

#7 Reduce radial effective stress to 1 mPa below in situ confining stress (3300 - 1000 kPa) allowing consolidation.

#10 Heat sample to 100 degrees Celcius and perform passive drained compression test while maintaining temperature.

REMARKS: oil 14.9% water 3.2% solid 81.9% (by mass)

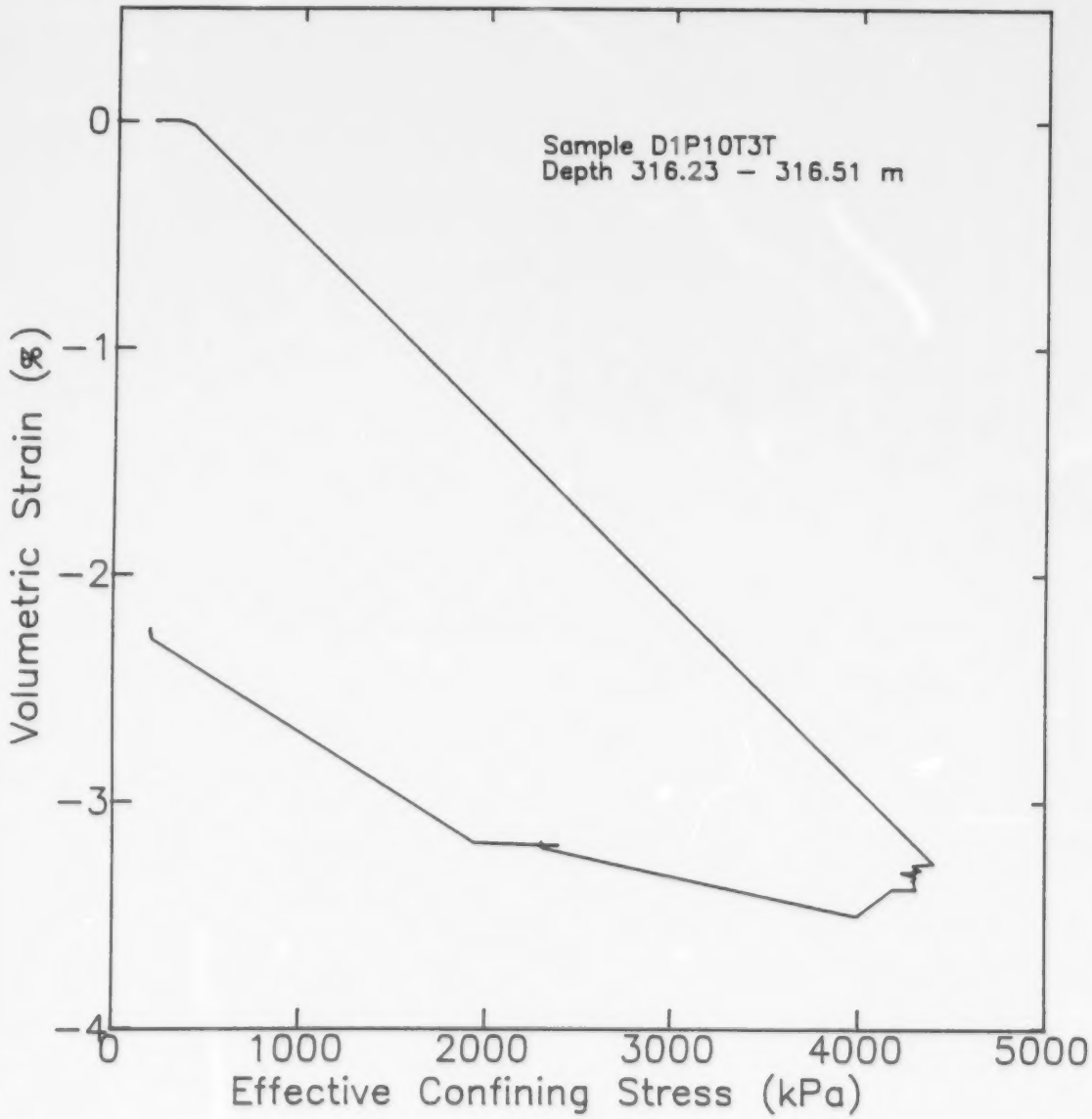
porosity before testing 44.4%

porosity in situ 36.9%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 20.5%

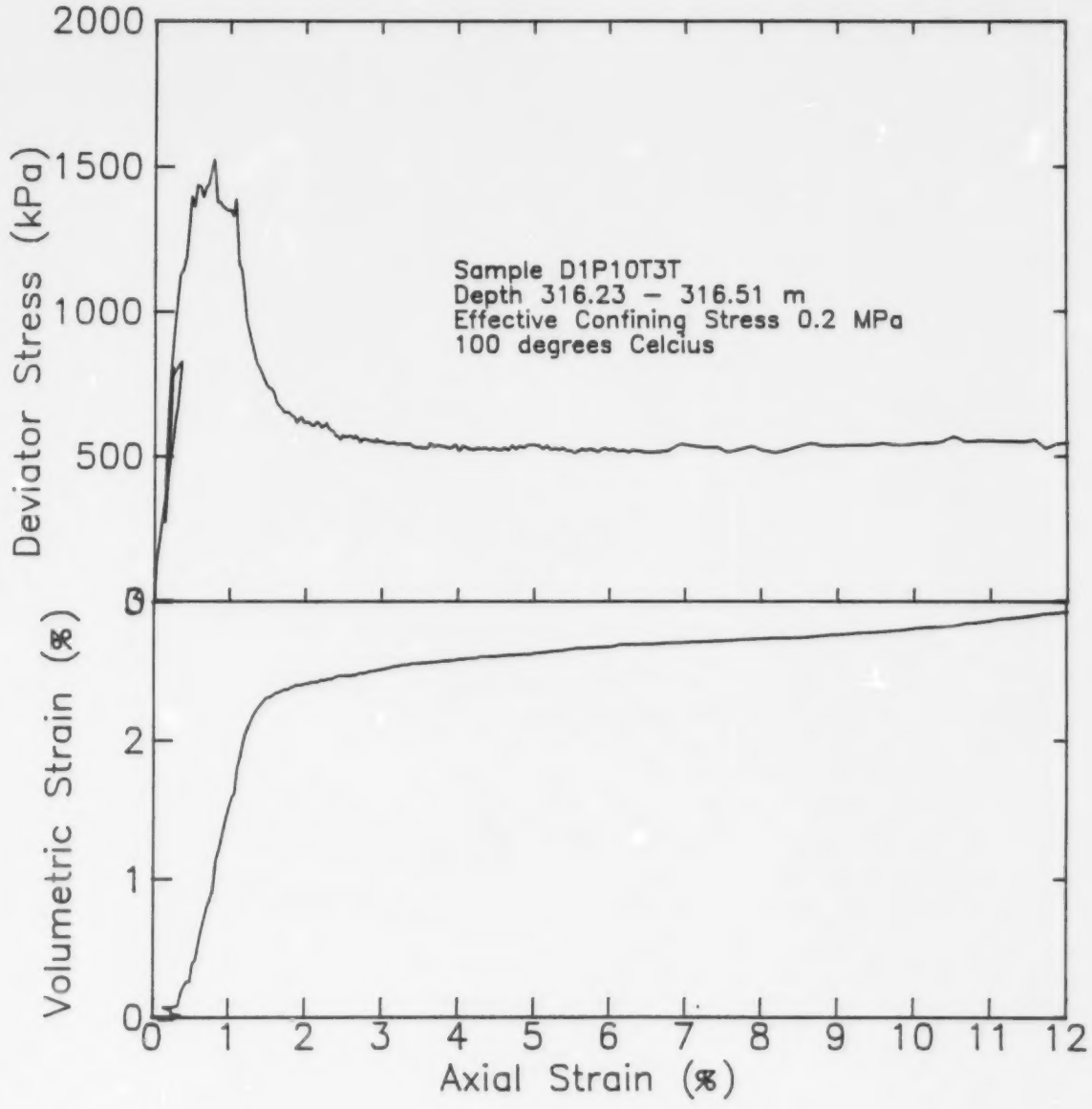
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure X



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

692-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: ____B1P10T3_____

DEPTH: ____316.23 - 316.51 m_____

GEOLOGICAL UNIT: __Laminar_____

VISUAL DESCRIPTION: _Medium oil sand, some shale, not continuous, extensive cracking, relatively nice _____
_sample, well shaped._____

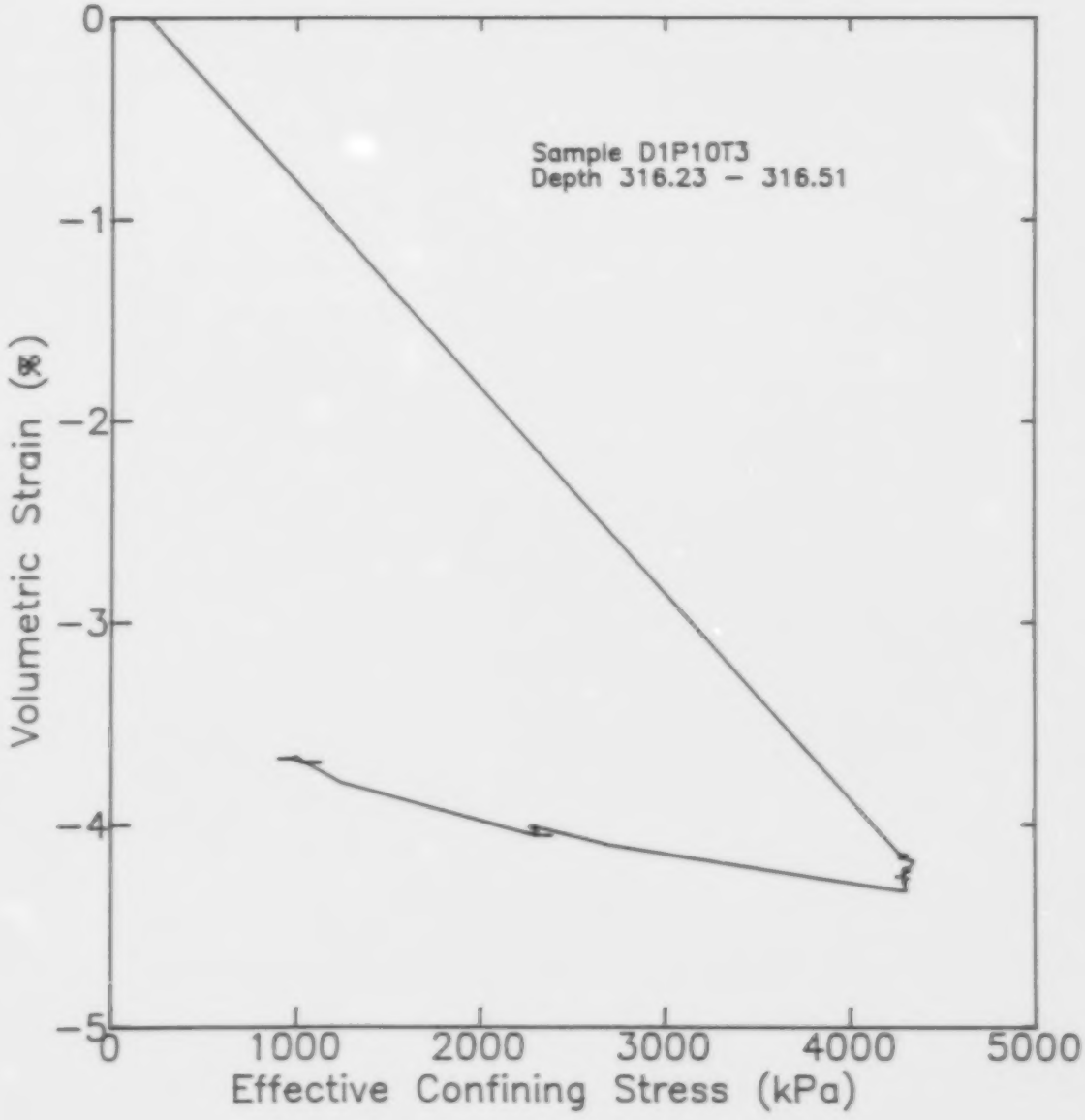
TYPE OF TEST: __Task 3_____

DATE TEST COMPLETED: _2 August 1990_____

DEVIATIONS FROM STANDARD TEST PROCEDURE: _#4 and #5____Effective confining stress = 200 kPa_____
_#6__Isotropic consolidation at 1 mPa above in situ confining____
____stress (3300 + 1000 kPa)._____
_#7__Reduce radial effective stress to 1 mPa below in situ_____
____confining stress (3300 - 1000 kPa) allowing consolidation.__

REMARKS: __oil 14.9%_water 3.2%_solid_81.9%_(by mass)_____
__porosity before testing 44.9%_____
__porosity in situ 36.9%_____
__(porosity is defined as ratio of void volume to total volume)_____
__index of disturbance 21.8%_____

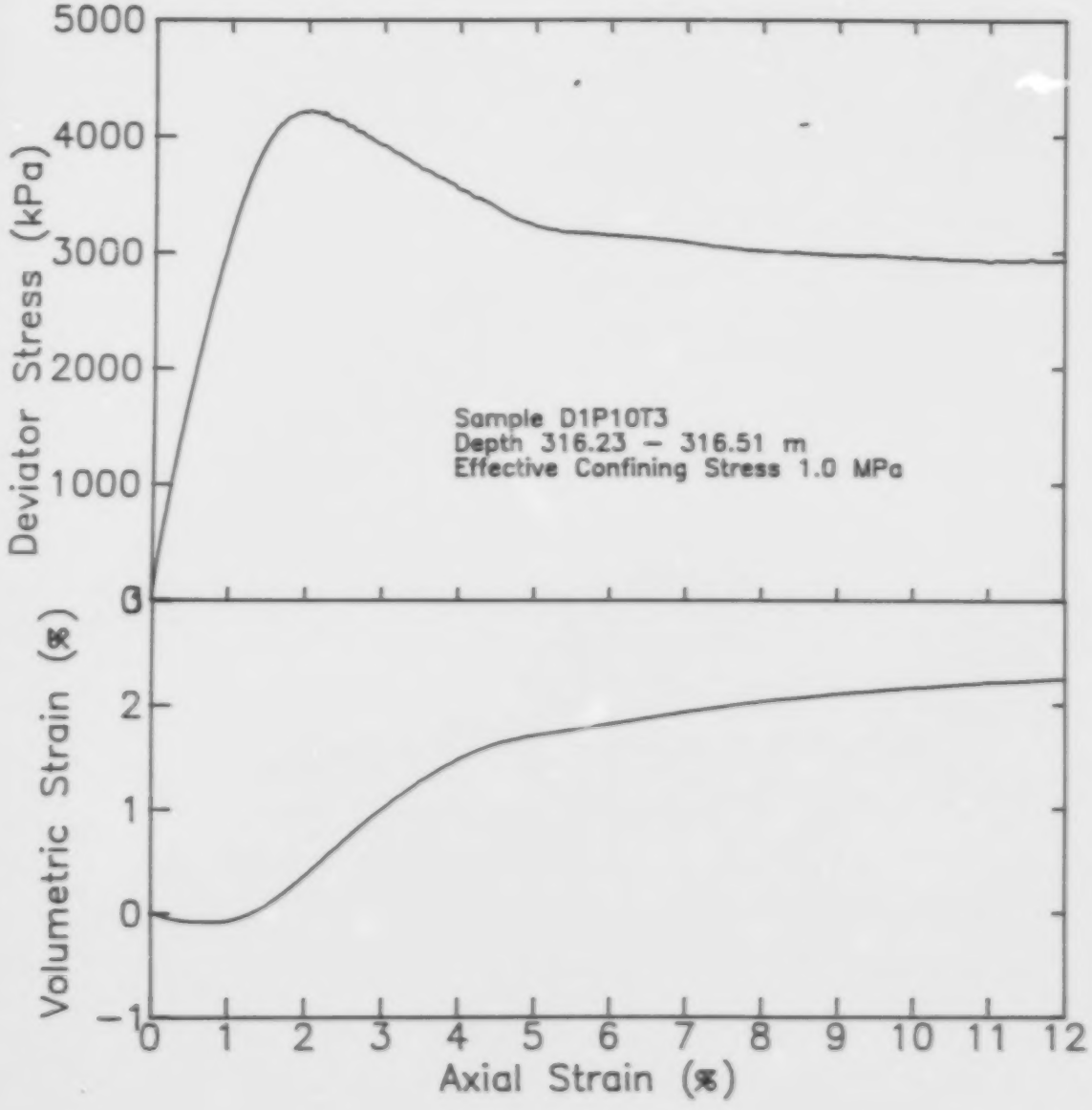
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: S1P7T3

DEPTH: 308.41 - 308.70

GEOLOGICAL UNIT: Shale

VISUAL DESCRIPTION: Excellent sample

TYPE OF TEST: Task 3

DATE TEST COMPLETED: 24 June 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 200 kPa

06 Isotropic consolidation at 1 mPa above in situ confining stress (3145 + 1000 kPa).

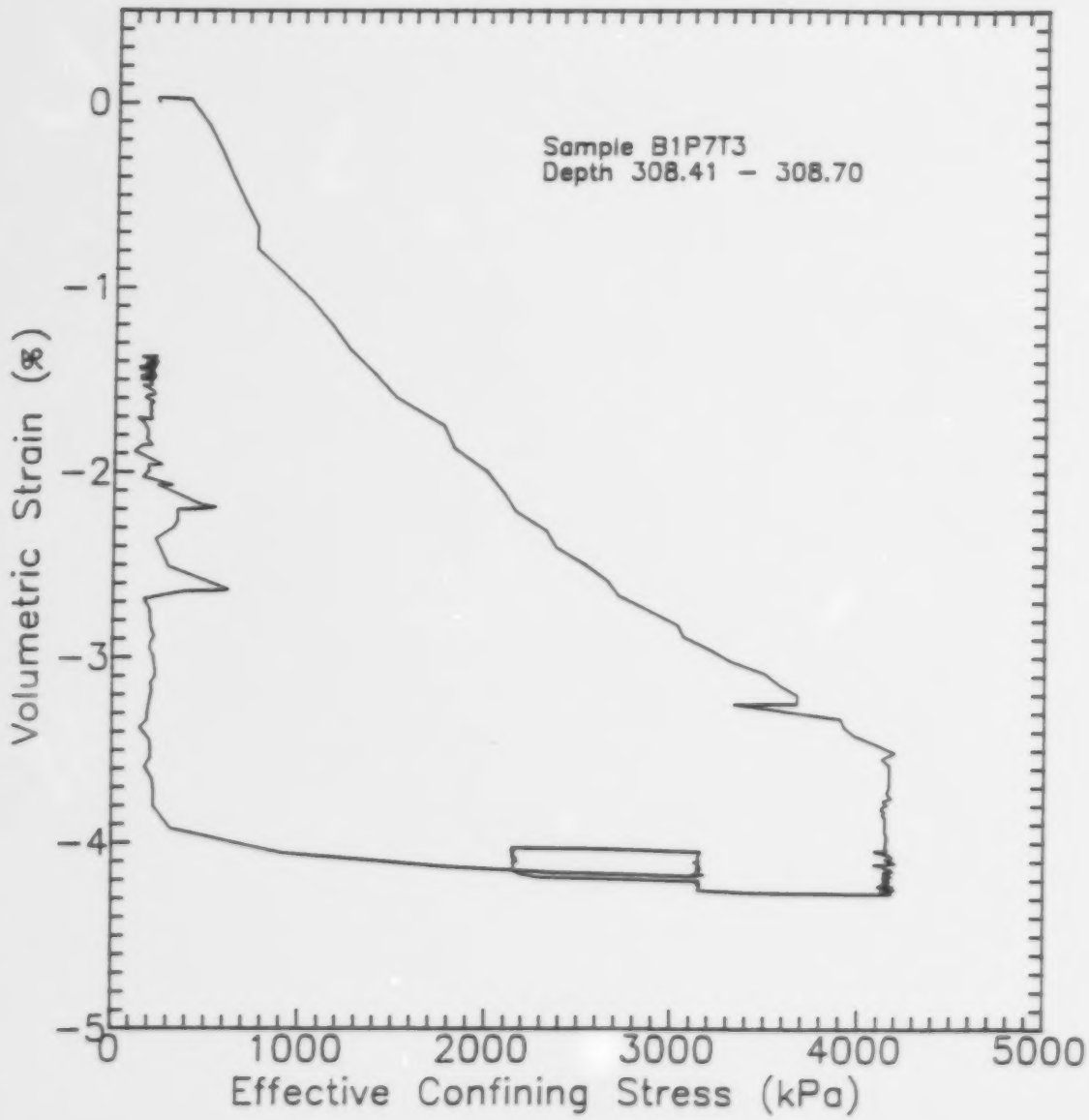
REMARKS: oil 0% water 11.6% solid 88.4% (by mass)

porosity before testing 29.3%

porosity in situ 26.3%

(porosity is defined as ratio of void volume to total volume)

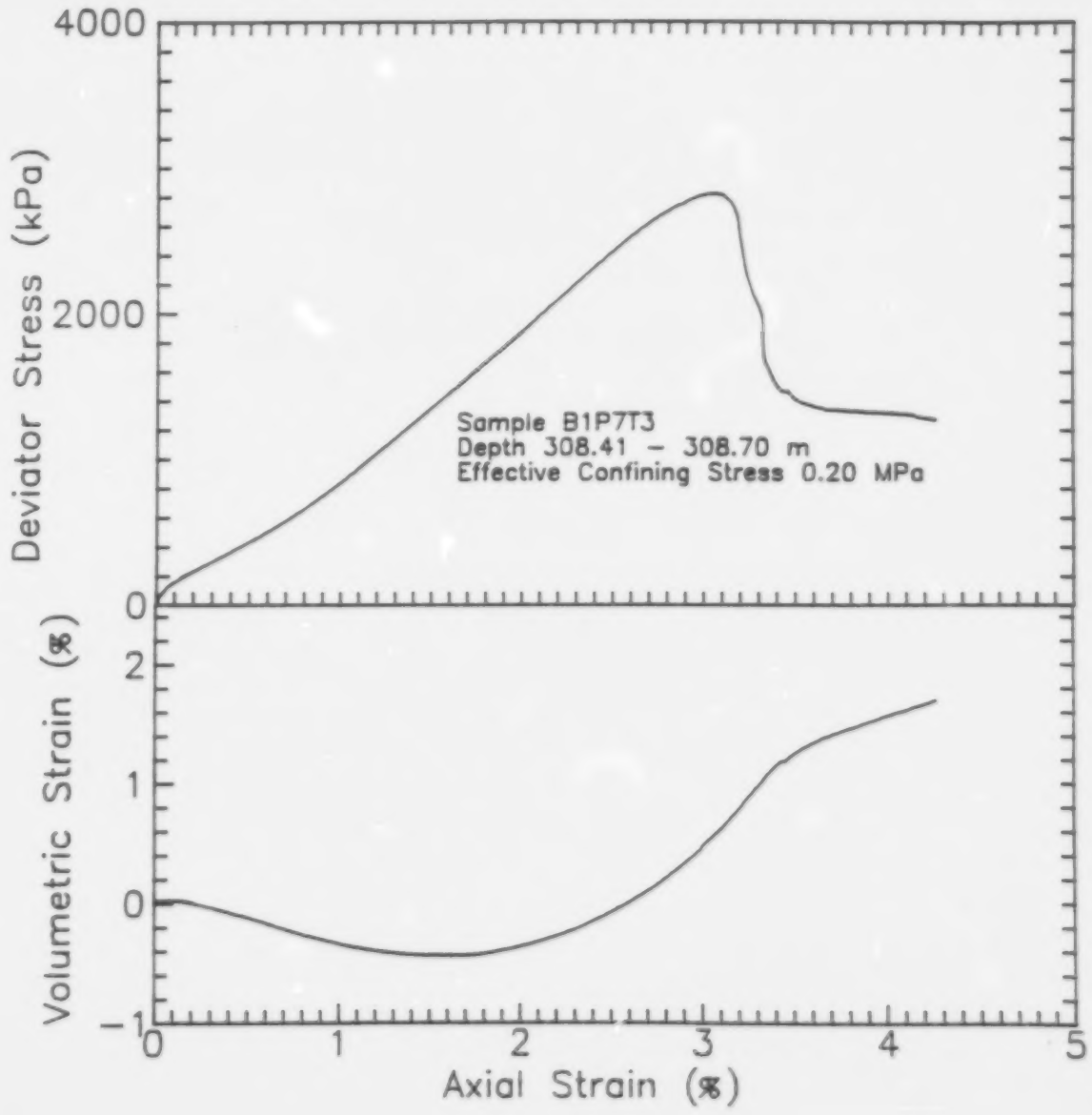
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

832-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: C1P1T3

DEPTH: 273.51 - 273.86

GEOLOGICAL UNIT: Shale

VISUAL DESCRIPTION: Good sample, laminations, shale

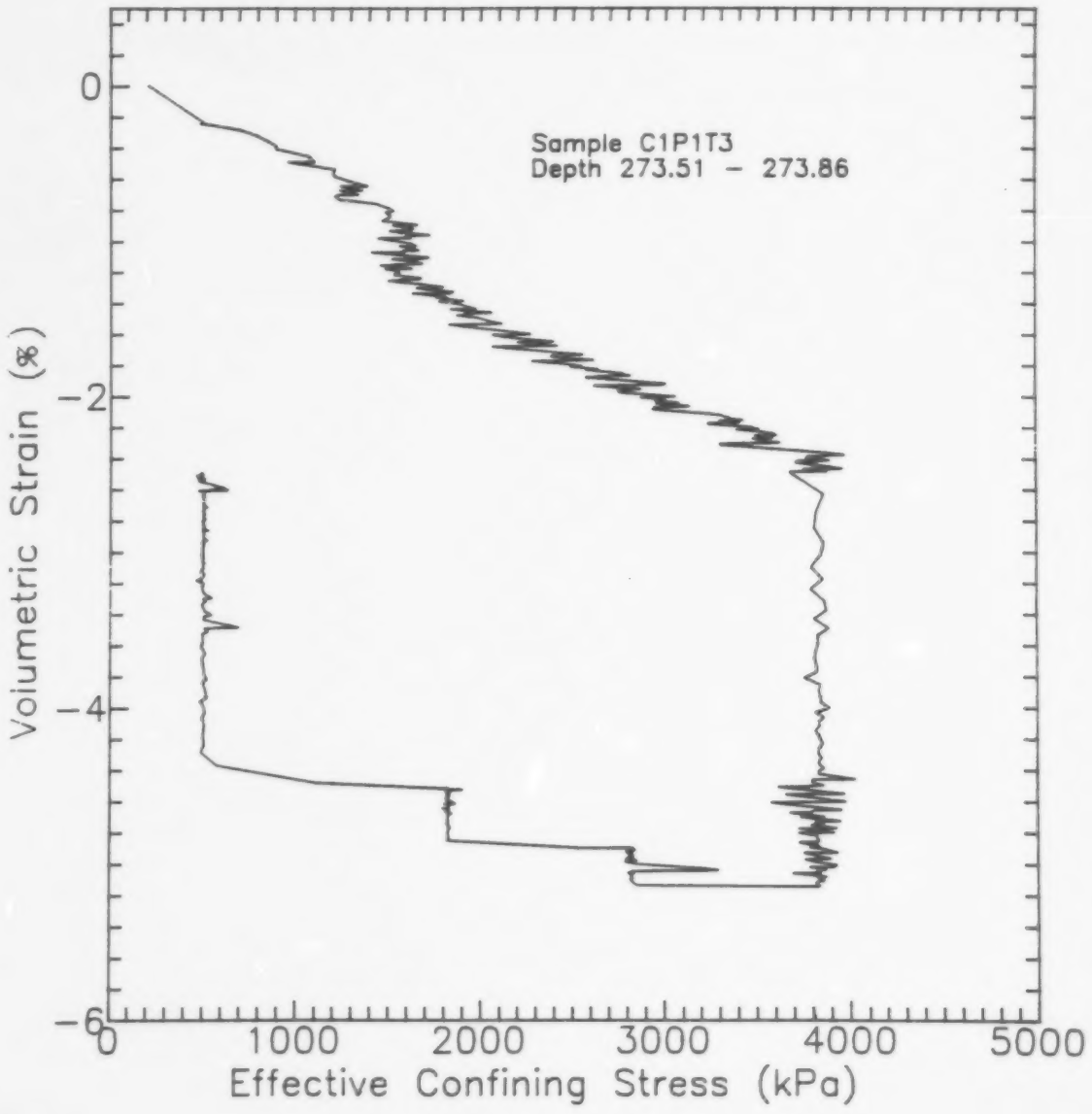
TYPE OF TEST: Test 3

DATE TEST COMPLETED: 28 June 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: 04 and 05 Effective confining stress = 500 kPa (20P)
06 Isotropic consolidation at 1 mPa above in situ confining
stress (2825 + 1000 kPa).
07 Reduce radial effective stress in 2 steps of 1000 kPa
allowing consolidation.

REMARKS: oil 0% water 11.3% solid 88.7% (by mass)
porosity before testing 28.3%
porosity in situ 24.6%
(porosity is defined as ratio of void volume to total volume)

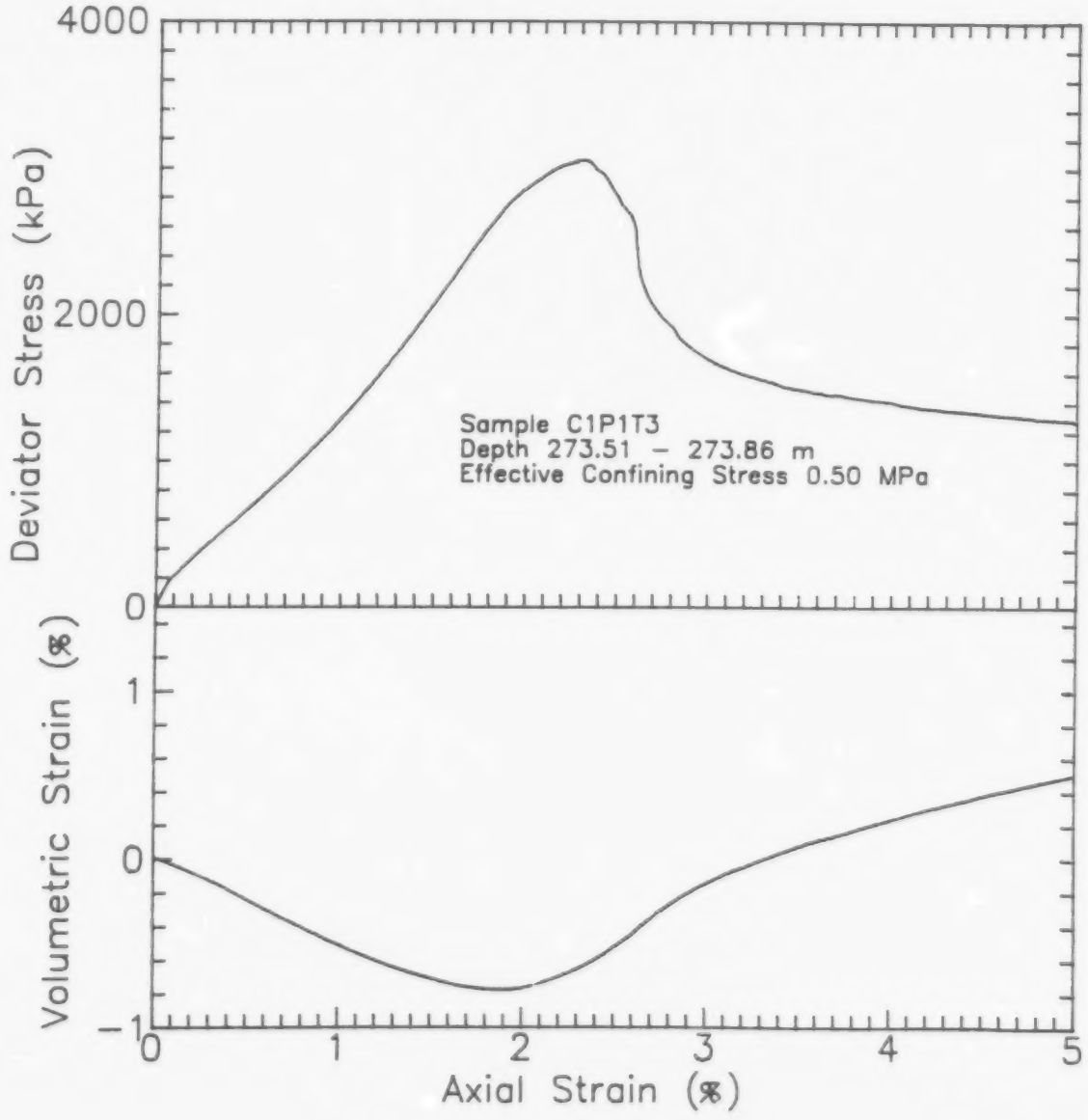
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: 02P1T3

DEPTH: 286.60 - 286.99

GEOLOGICAL UNIT: Shale

VISUAL DESCRIPTION:

TYPE OF TEST: Task 3

DATE TEST COMPLETED: 2 July 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #4 and #5 Effective confining stress = 200 kPa

#6 Isotropic consolidation at 1 mPa above in situ confining stress (2940 + 1000 kPa).

#7 Reduce radial effective stress to 1 mPa below in situ confining stress (2940 - 1000 kPa) allowing consolidation.

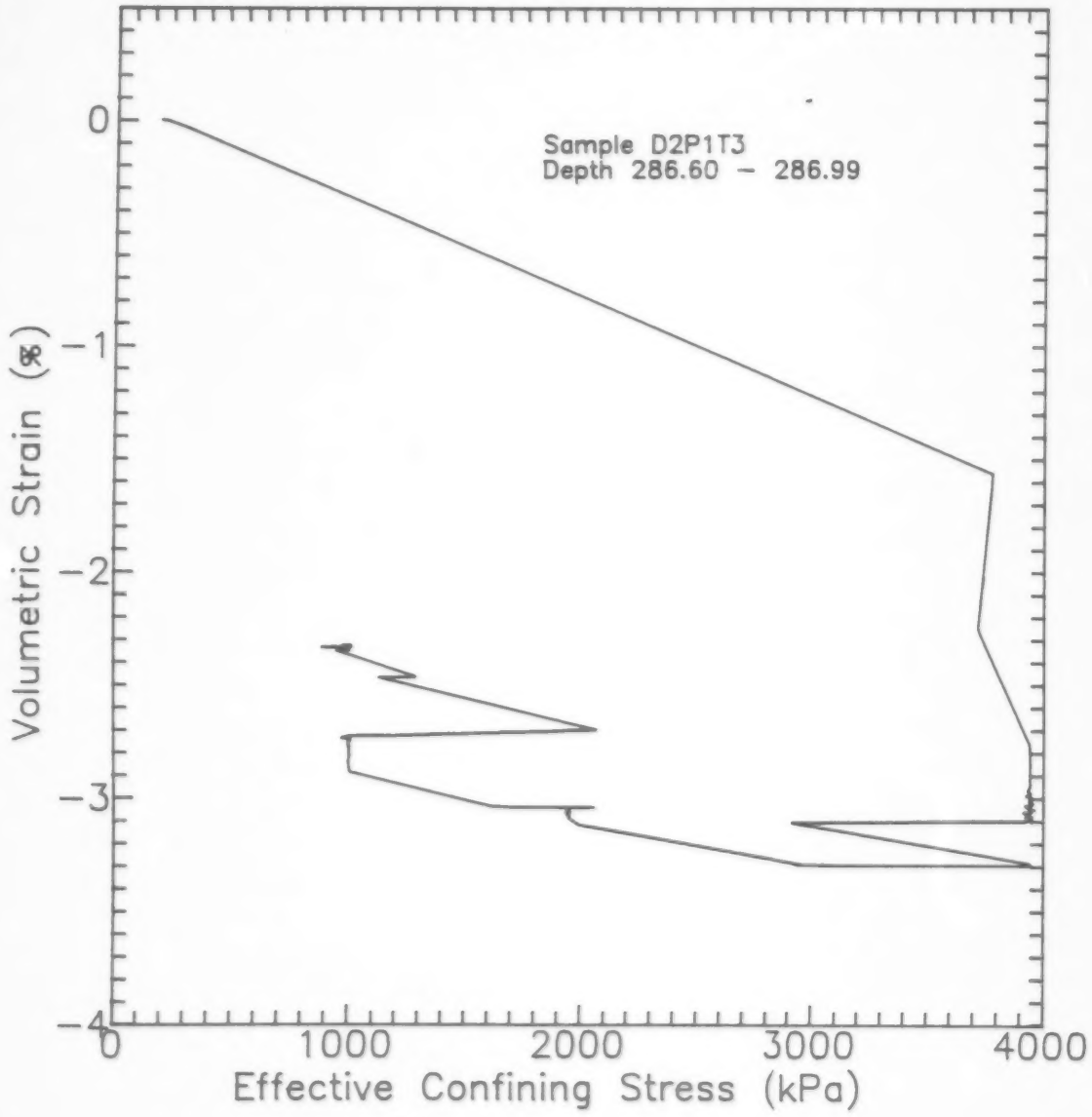
REMARKS: oil 0% water 11.7% solid 88.3% (by mass)

porosity before testing 30.7%

porosity in situ 28.4%

(porosity is defined as ratio of void volume to total volume)

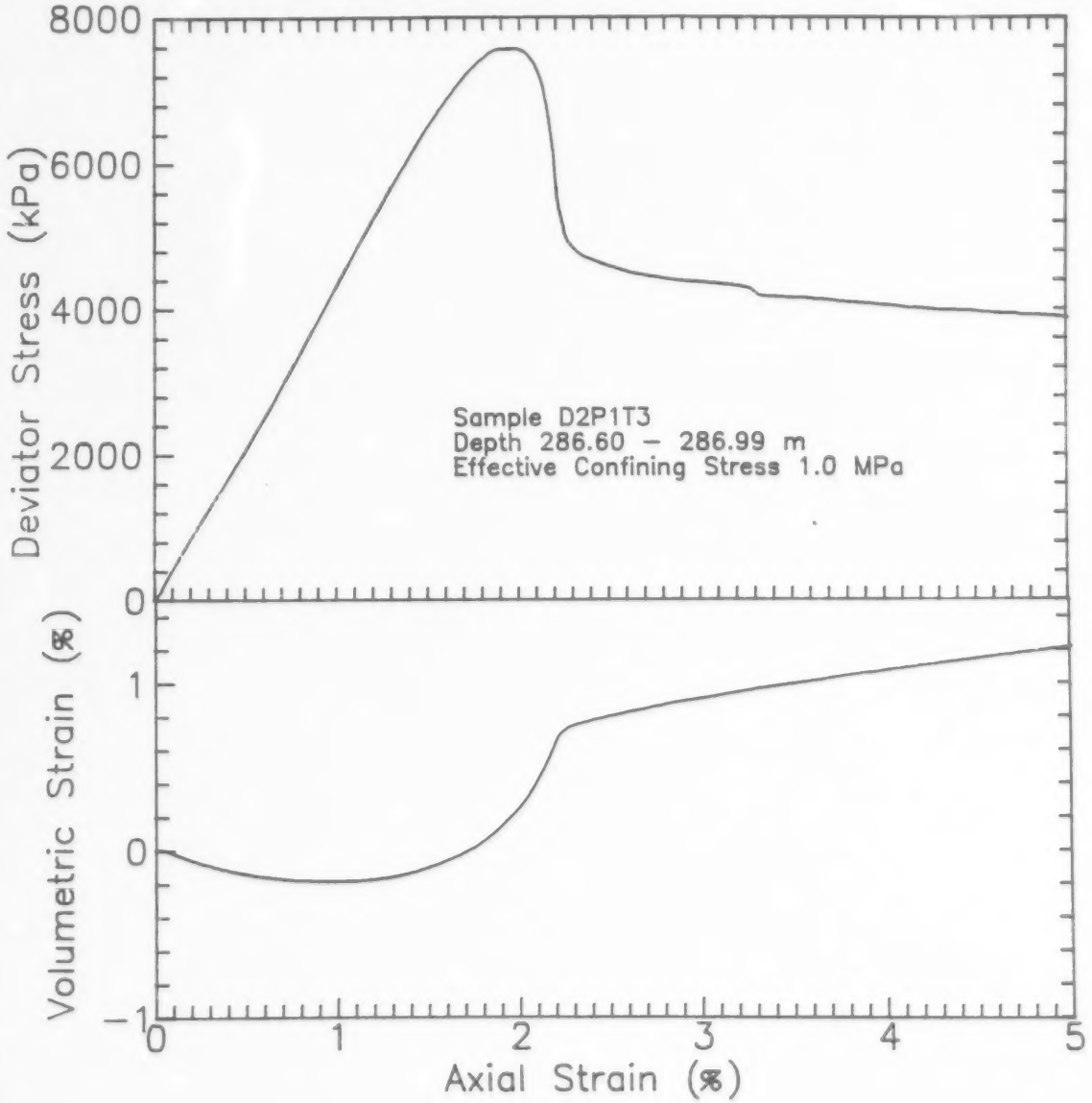
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D1P3T1 (D1P3T3A)

DEPTH: 290.81 - 291.05 m

GEOLOGICAL UNIT: Clasts

VISUAL DESCRIPTION: Some disturbance cracking

TYPE OF TEST: Task 3, 3 cycles

DATE TEST COMPLETED: 23 August 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #4 and #5 Effective confining stress = 200 kPa

#6 Isotropic consolidation at 1 mPa above in situ confining stress (3045 + 1000 kPa).

#7 Reduce radial effective stress to 1 mPa below in situ confining stress (3045 - 1000 kPa) allowing consolidation.

#8 B test carried out at strain stress

#10 and 11 Repeat for 2 additional cycles

REMARKS: oil 15.1% water 2.8% solid 82.1% (by mass)

porosity before testing 44.5%

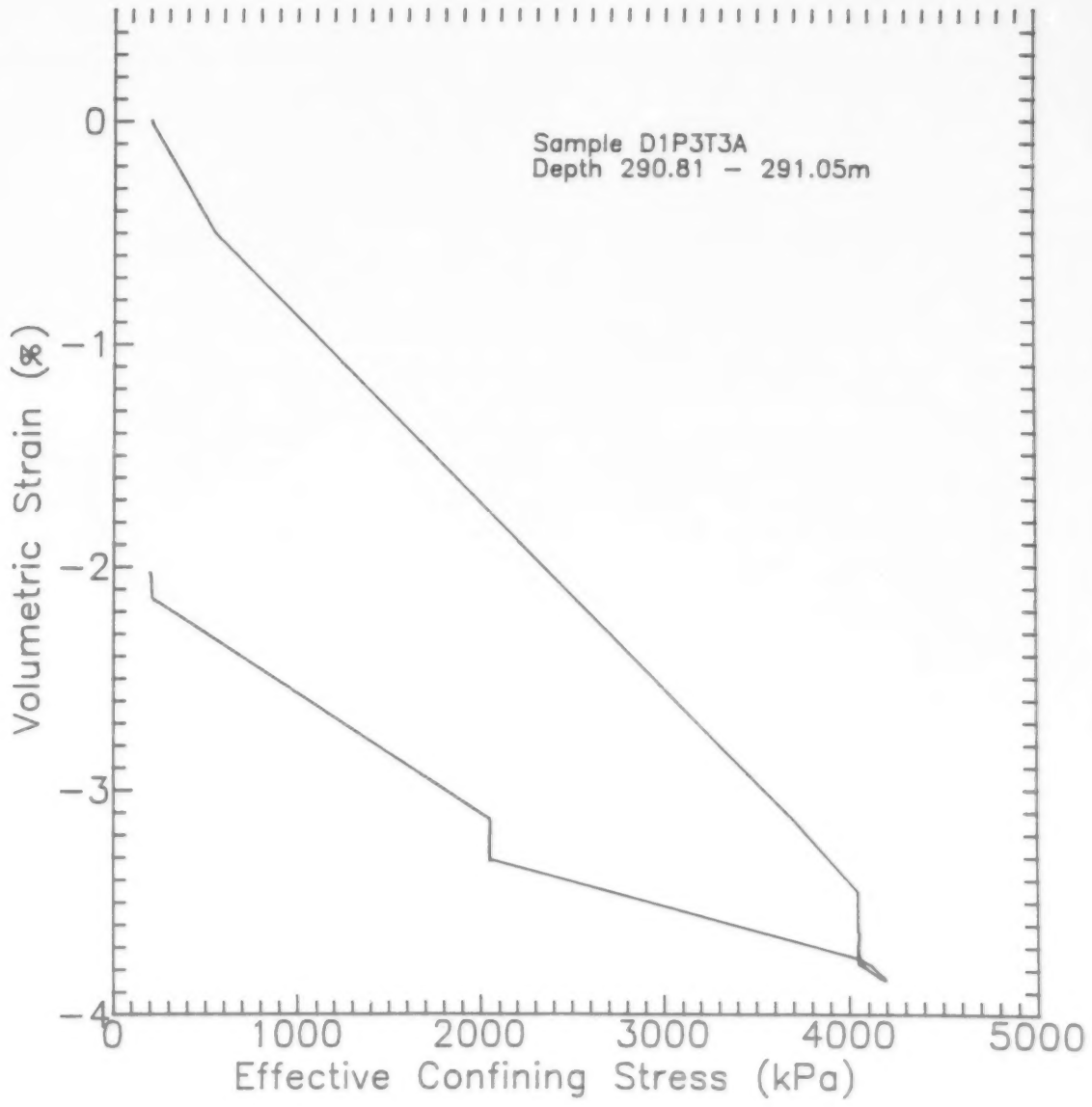
porosity in situ 36.6%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 21.6

A slow leak was present during bulk compressibility cycle

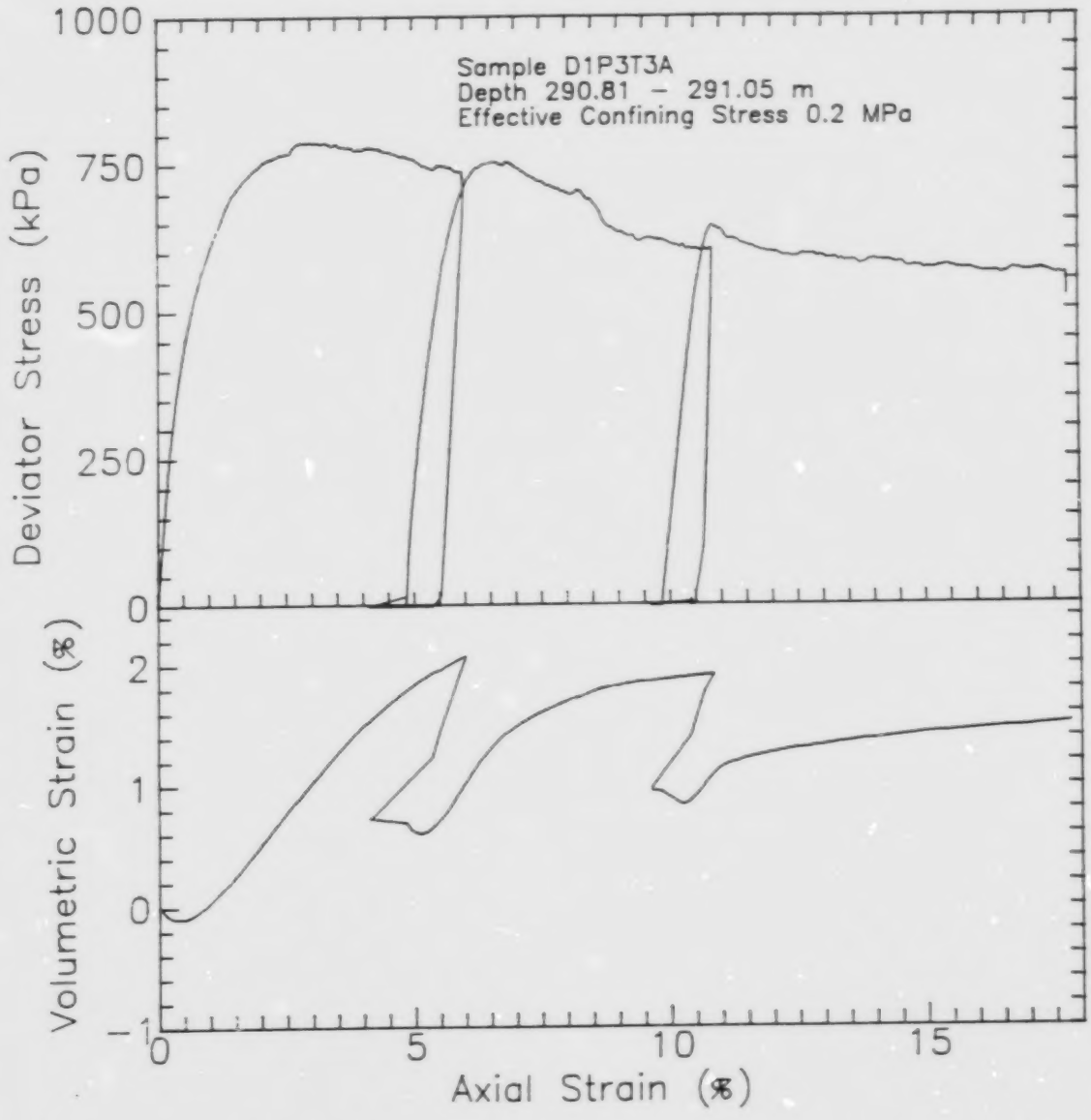
Figure



Task 3 – Cyclic Compressibility Test

PEC No. _____ DRAWN _____ REVIEWED _____ DATE _____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Golder Associates Ltd.
CONSULTING ENGINEERS

892-2082

LABORATORY TEST SUMMARY SHEET

SAMPLE NUMBER: D1P3T2 (D1P3T3B)

DEPTH: 290.81 - 291.05 m

GEOLOGICAL UNIT: Clasts

VISUAL DESCRIPTION: Good sample, laminations, partial extraction done on sample

TYPE OF TEST: Task 3, 3 cycles

DATE TEST COMPLETED: 28 August 1990

DEVIATIONS FROM STANDARD TEST PROCEDURE: #4 and #5 Effective confining stress = 200 kPa

#6 Isotropic consolidation at 1 mPa above in situ confining stress (3045 + 1000 kPa).

#7 Reduce radial effective stress to 1 mPa below in situ confining stress (3045 - 1000 kPa) allowing consolidation.

#10 and 11 Repeat for 2 additional cycles

REMARKS: oil 15.1% water 2.9% solid 82.1% (by mass)

porosity before testing 39.0%

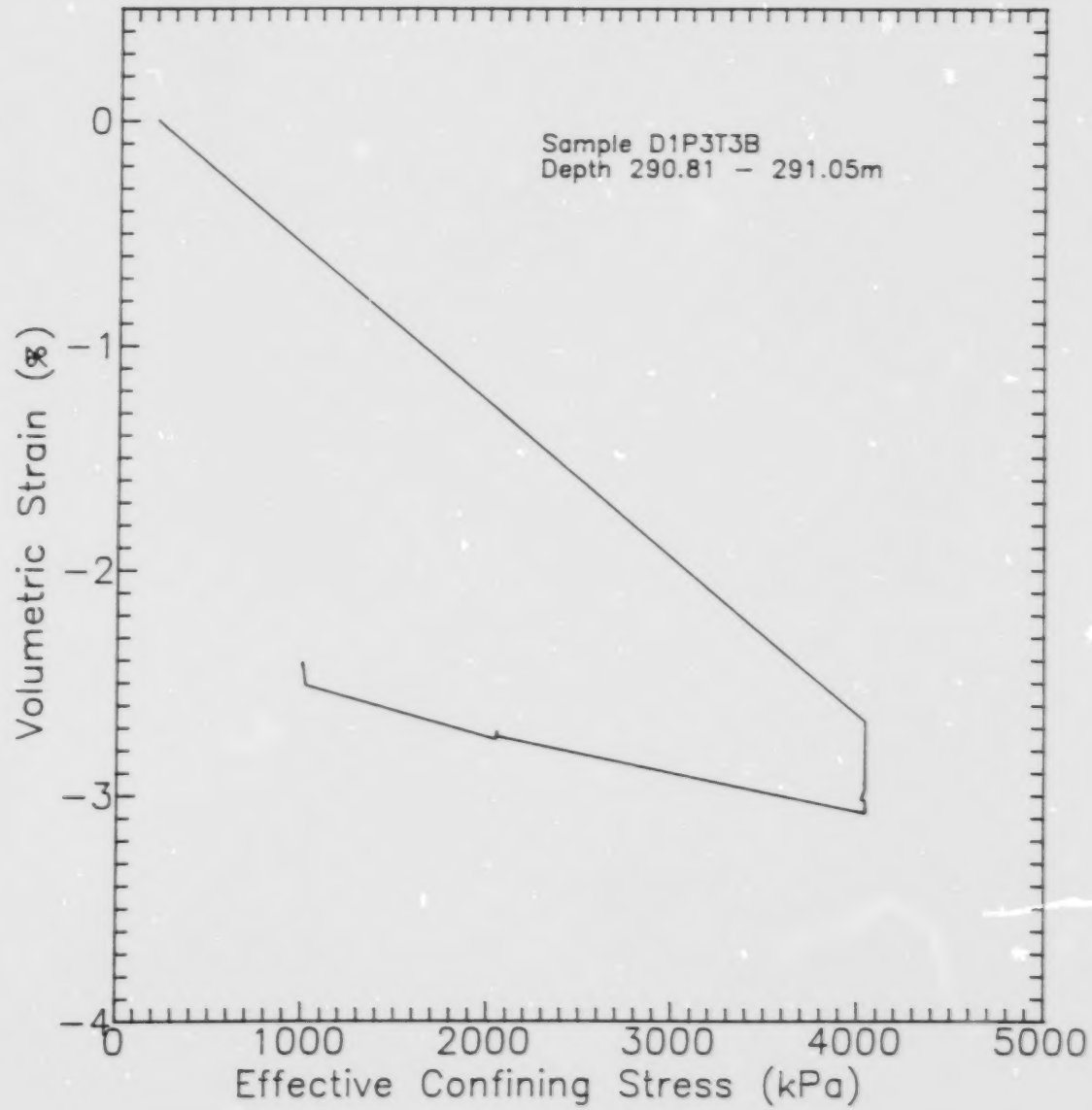
porosity in situ 36.6%

(porosity is defined as ratio of void volume to total volume)

index of disturbance 6.7

A slow leak was present during test

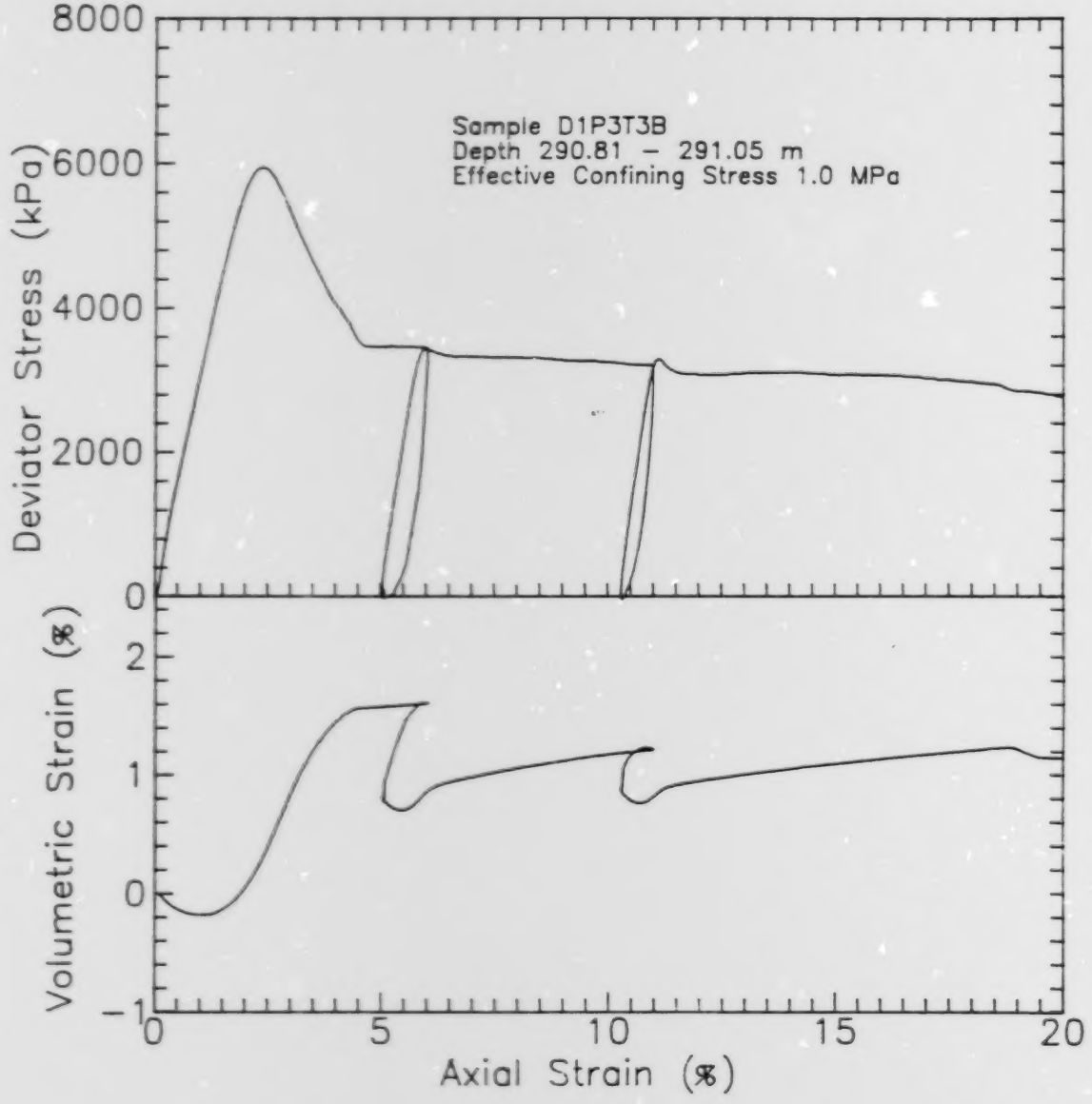
Figure



Task 3 – Cyclic Compressibility Test

PROJECT No. ____ DRAWN ____ REVIEWED ____ DATE ____

Figure



Task 3 – Drained Passive Compression Test

PROJECT No. _____ DRAWN _____ REVIEWED _____ DATE _____

Volume

2

PETRO-CANADA

23440-9-9264-01-SQ
BOOK TWO OF TWO

CONTRACT SERIAL NO. 23440-9-9264-01-SQ
DSS REQUISITION NUMBER 23440-9-9264
CONTRACTOR: PETRO-CANADA LTD.
TITLE GEOTECHNICAL TESTING OF OILSANDS
BOOK TWO OF TWO

GEOTECHNICAL TESTING OF OILSANDS

BOOK TWO OF TWO

98 pp

MICROMEDIA

PCEJ HANGINGSTONE 16-27

VARIOUS WELLS X-RADIOGRAPHY

WESTERN ATLAS CORE LABORATORIES

Western Atlas International
A Litton/Dresser Company

CORE LABORATORIES

November 6, 1990

Petro-Canada Inc.
#40 Research Place N.W.
Calgary, Alberta
T2L 1Y6

Attention: Nobu Fokushima

Subject: **PCI PCEJ Hangingstone 16-27 - Various Wells**
X-Radiography - 39 Plugs - 4 Orientations
File # 52135-90-3559

X-Radiography is a non-destructive technique, using X-rays, to study internal structures in rock material. Based on the attenuation of X-rays through a sample, an image is produced on special photographic film, recording lateral and vertical density variations which reveal changes in grain size, rock fabric, composition, and cementation.

Thirty nine (39) samples, wrapped in a latex sleeve, were received from Golder Associates Ltd. which had been subjected to various Geotechnical Test, arrived at Core Laboratories in their frozen state. X-Radiography was performed through the latex sleeve, frozen, to reveal the type of sand (homogeneous sand, shaly/sand, sandy/shale) and the location and appearance of induced fractures. Four angles (arbitrary 0^0 and subsequent 45^0, 90^0 135^0) were subjected to 80 kV and 8.45 Ma at a distance of 150 cm for 3:00 minutes. The above parameters were set for all 39 samples so as to compare attenuation from sample to sample. Any area on the negative plate portraying lighter image represents denser material or more compaction. Dark lines traversing the samples indicate induced fractures.

A certain advantage would have been gained if all samples in question would have been marked (arbitrary 0^0 and subsequent 45^0, 90^0, 135^0 and top and bottom) and X-rayed before Geotechnical Testing. Than, a comparison before and after analysis would have been realized so as to compare fracture direction.

Western Atlas Canada Ltd.
1540 – 25th Avenue N.E., Calgary, Alberta, Canada T2E 7R2 (403) 250-4000 Fax: (403) 250-5120

All in all, X-Radiography has proven to be a very useful tool, able to visualize internal structures and failures. Together, the X-rays supplied by Core Laboratories and the data/analysis supplied by Golder Associates Ltd. will assist Petro-Canada Inc. engineers better understand grain behavior/direction after failure.

Yours truly,

CORE LABORATORIES

Charles Savoie
Supervisor
Geological Sciences
X-radiograghy/Imaging

CS:bjf

Photography

PETRO-CANADA INC.

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

SELECTED SAMPLES FROM PRESERVRED CORE

X-RADIOGRAPHY AT 0°

1990 10 30 **52135-90-3559**

CORE
LABORATORIES

WELL IDENTIFICATION SHEET

150 cm
80Kv
8.45Ma
3.00 mins.

Oct 26, 1990

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 1			
	B1 P4 T1	B1 P4 T1 (After Leak)	(Group 1-1)
	B1 P8 T1	B2 B7 T1	(Group 1-2)
Page 2			
	B2 P3 T1	B2 P1 T1	(Group 2-1)
	C1 P2 T1	C3 P2 T1	(Group 2-1)
	C1 P4 T1	D2 P6 T1	(Group 2-2)
Page 3			
	C3 P3 T1		(Group 3-1)
Page 4			
	B2 P1 T2 (1/2 sample)		(Group 5-1)
	D1 P9 T2B (Portion of sample too friable to X-ray all angles)		(Group 5-2)
	C3 P3 T2		(Group 6-1)
Page 5			
	B1 P4 T3 (1/2 sample)	B2 P3 T3 (split sample)	(Group 7-1)
	B2 P1 T3 (split sample)	D1 P7 T3	(Group 7-1)
	D2 P4 T3	C1 P2 T3	(Group 7-1)
Page 6			
	B1 P8 T3		(Group 7-2)
	B2 P7 T3		(Group 7-2)
	C1 P4 T3		(Group 7-2)
Page 7			
	C3 P2 T3		(Group 8-1)
	D1 P7 T3B	D2 P4 T3B	(Group 9-1)
	D1 P7 T3	D2 P4 T3	(Group 10-1)

CORE
LABORATORIES

WELL IDENTIFICATION SHEET

150 cm
80Kv
8.45Ma
3.00 mins.

Oct 26, 1990

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 8

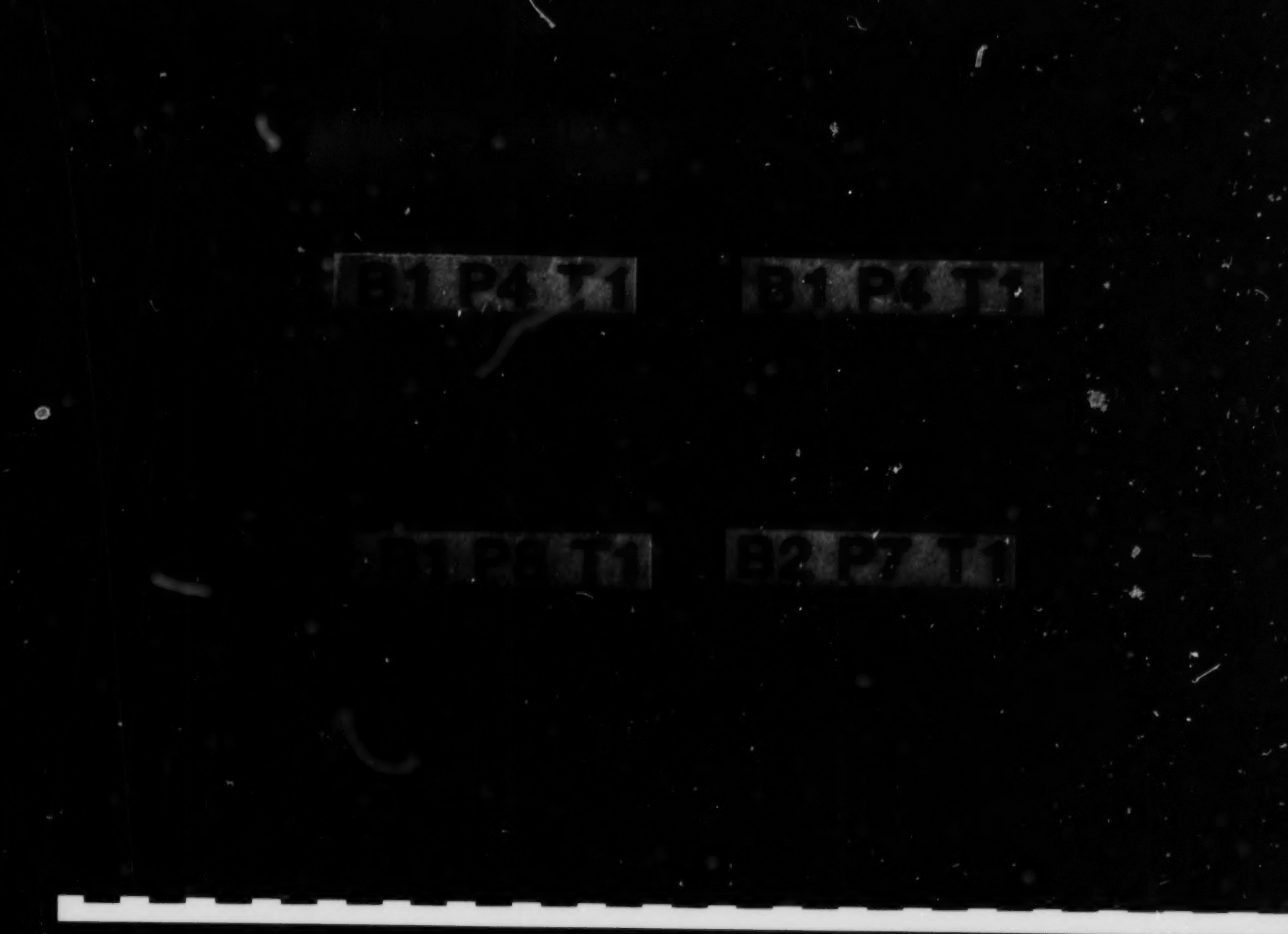
D1 P3 T3(1.0m)	D1 P3 T3(0.20m)	(Group 11)
D2 P8 T3B	D2 P8 T3	(Group 12-1)
D1 P10 T3		(Group 12-1)

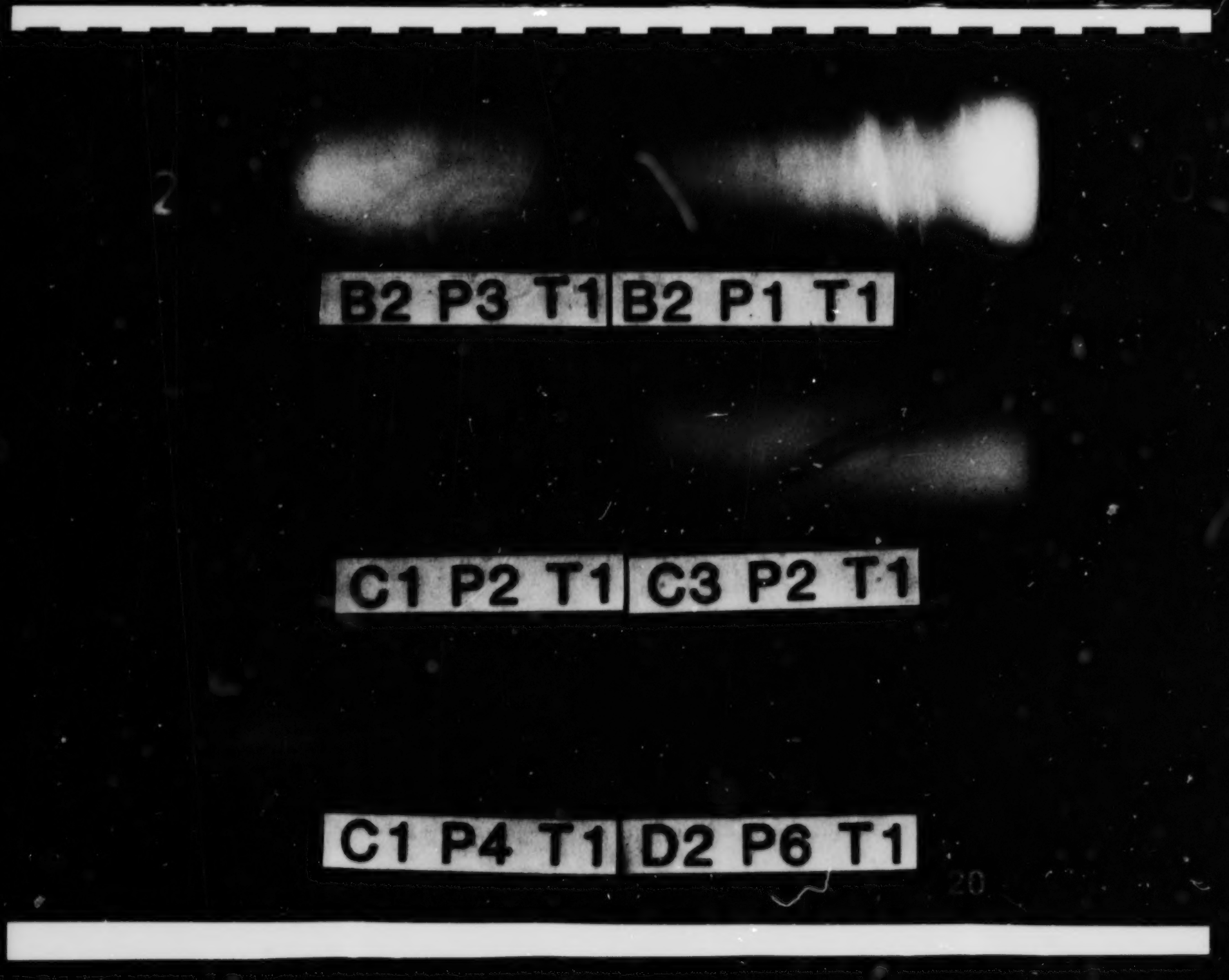
Page 9

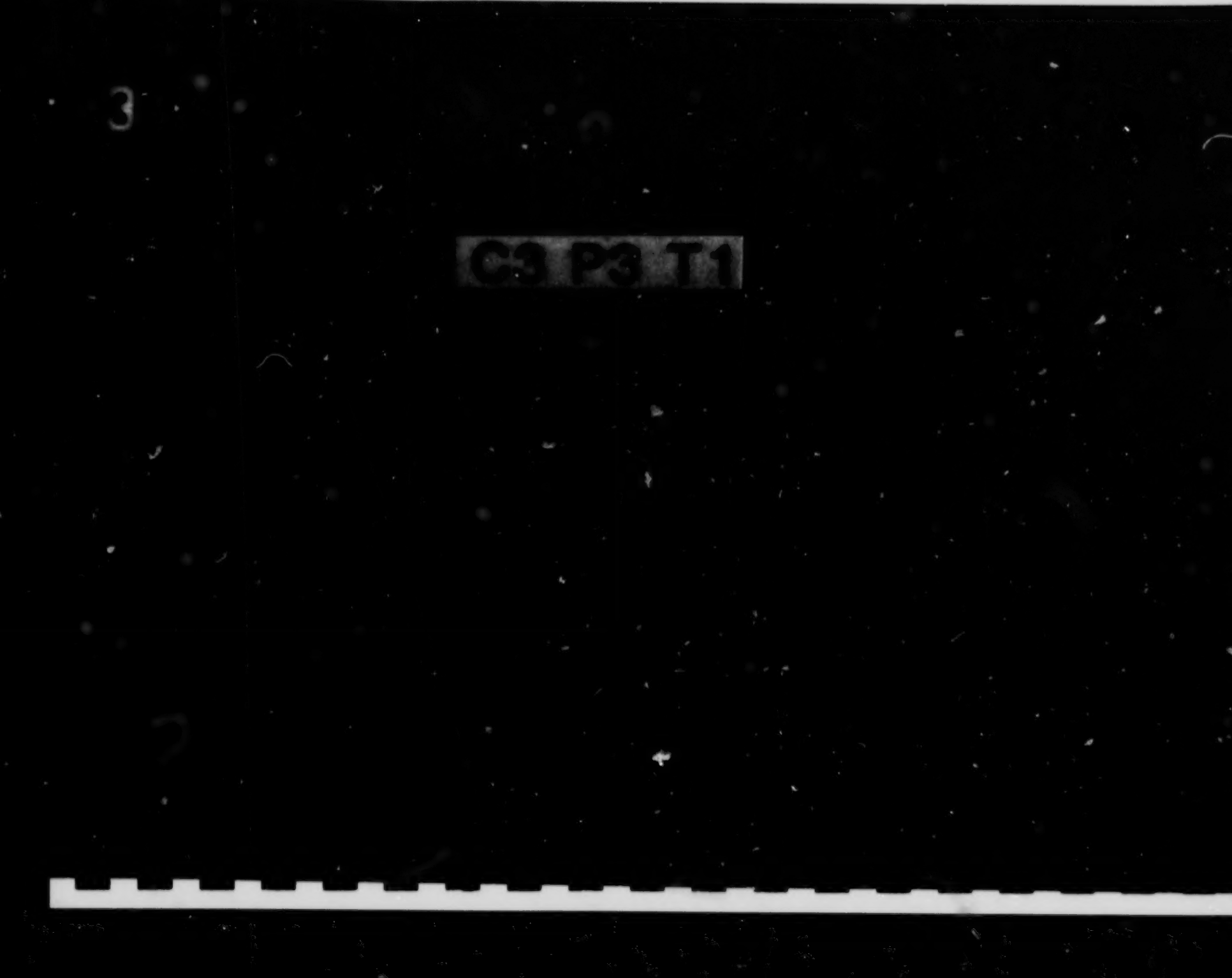
D1 P10 T3T	D2 P8 T3T	(Group 12-2)
B1 P2 T3	B1 P7 T3	(Group 13)
C1 P1 T3	D2 P1 T3	(Group 13)

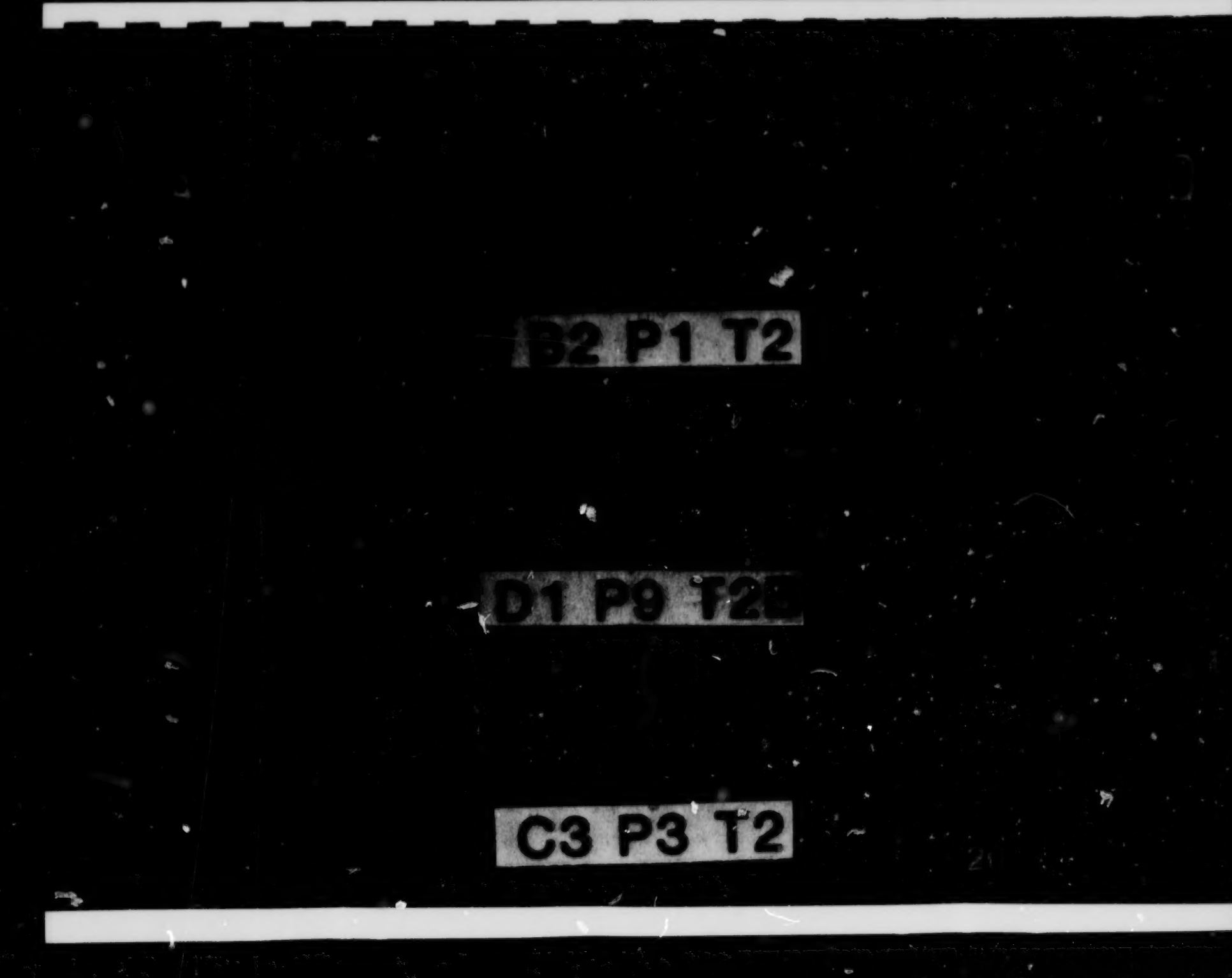
Ken Turner
Photo Technician

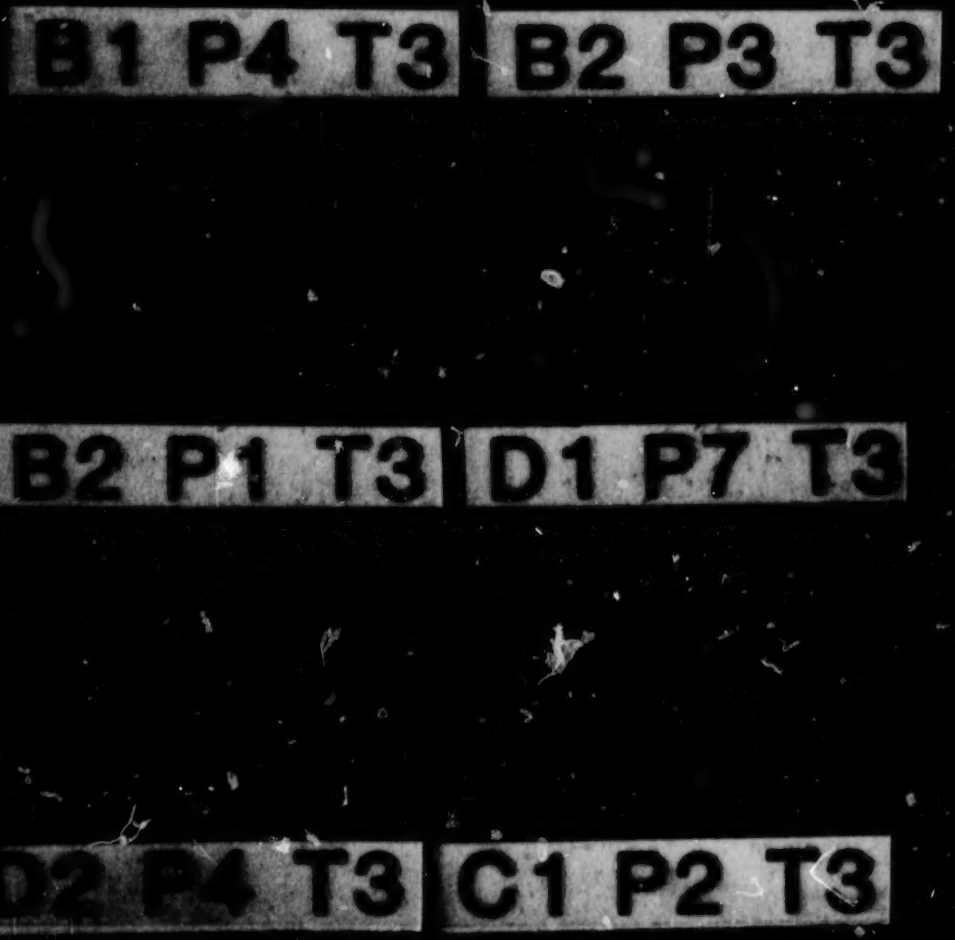
Charles Savoie
Supervisor Geological Sciences
X-Radiography/Imaging

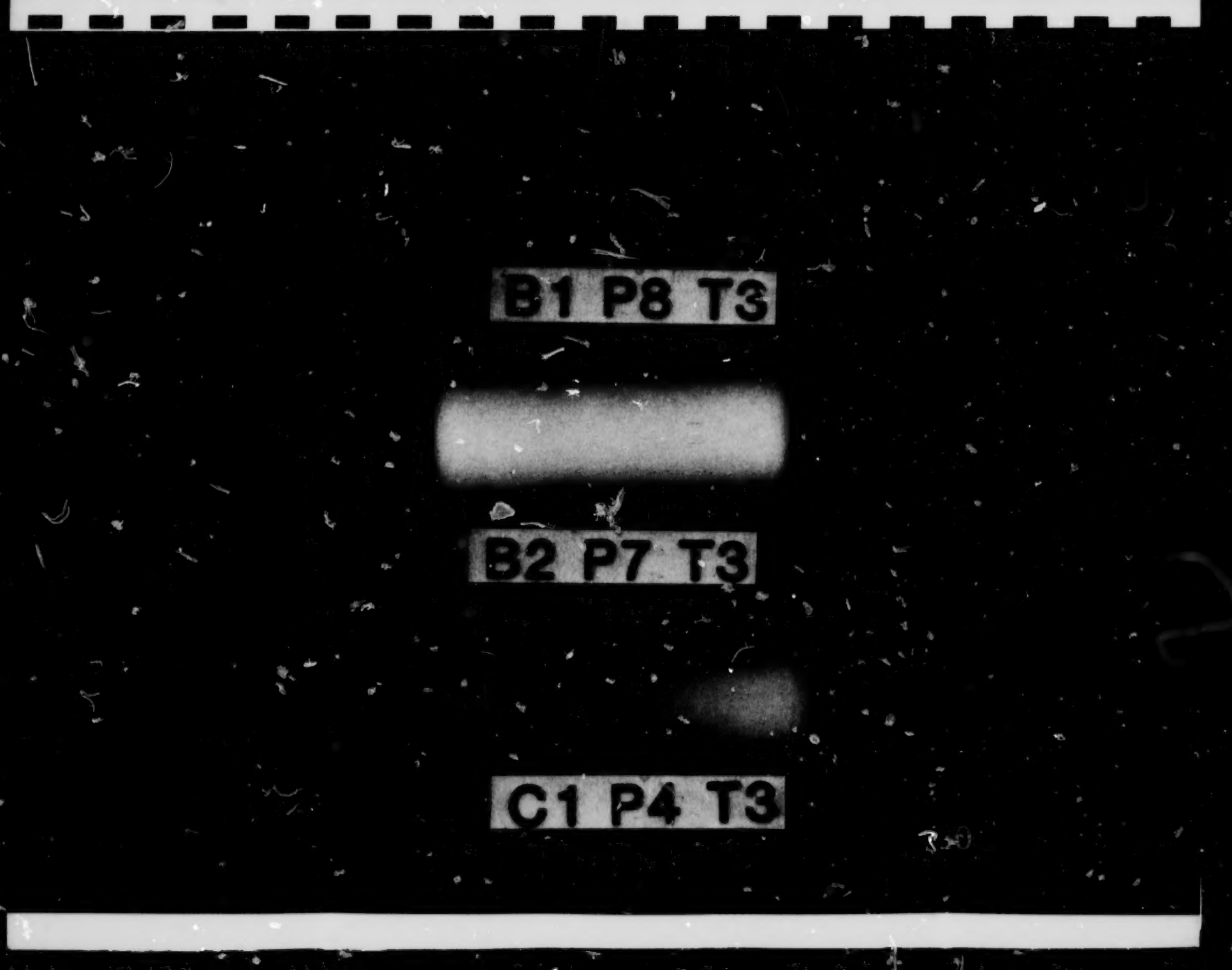

B1 R4 T1
B1 R3 T1
B1 R4 T1
B2 R2 T1

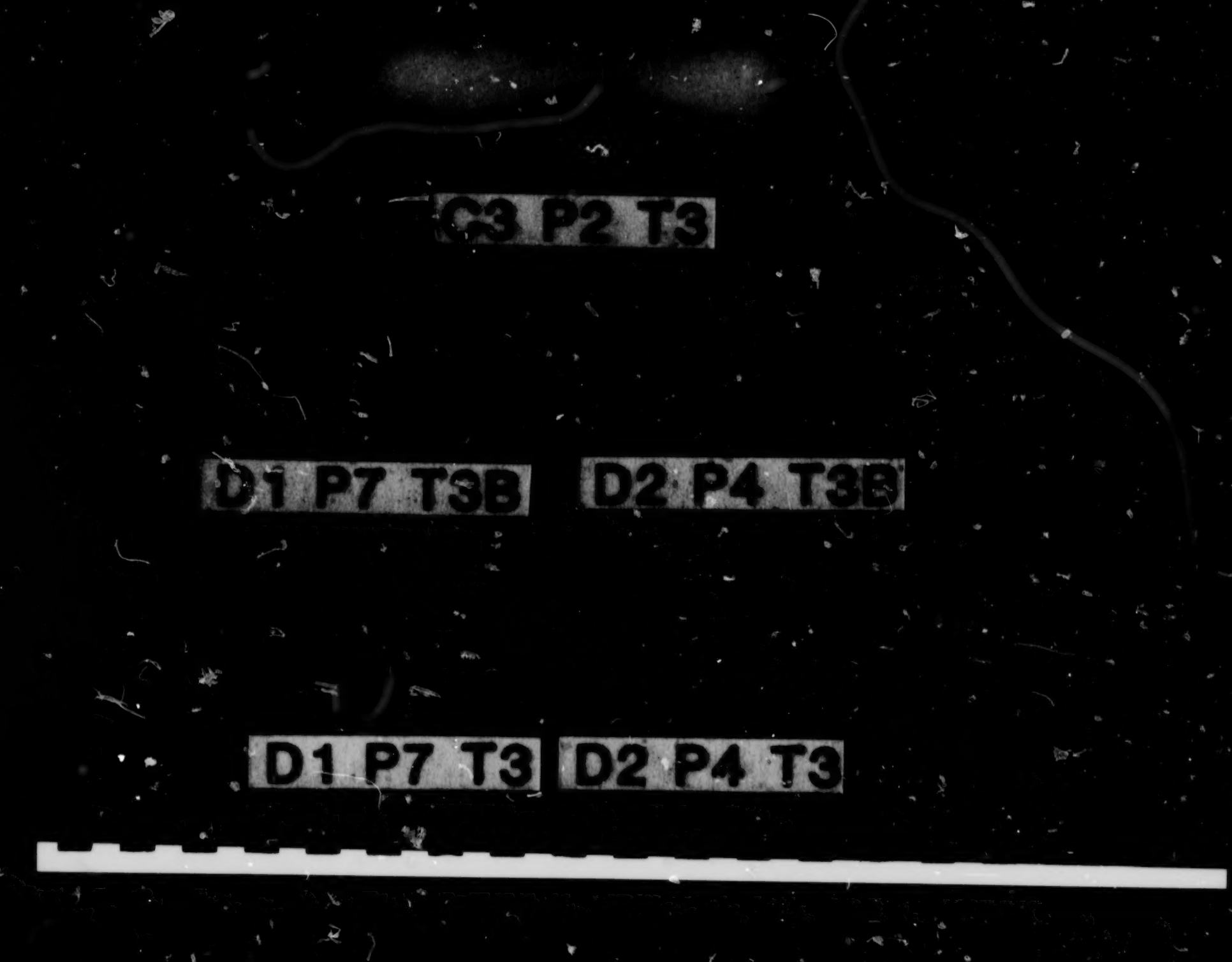

B2 P3 T1
B2 P1 T1
C1 P2 T1
C3 P2 T1
C1 P4 T1
D2 P6 T1

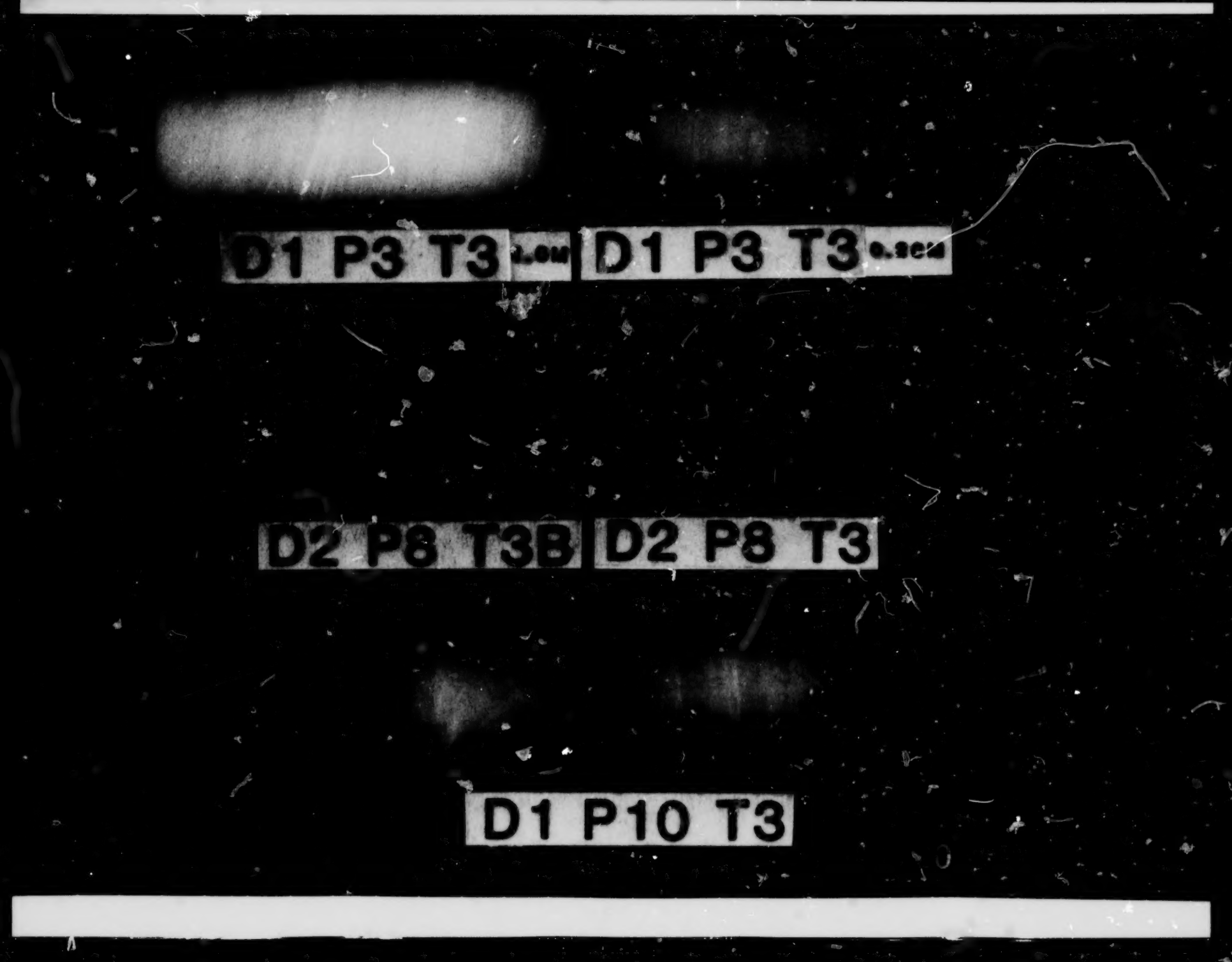

C3 P3 T1

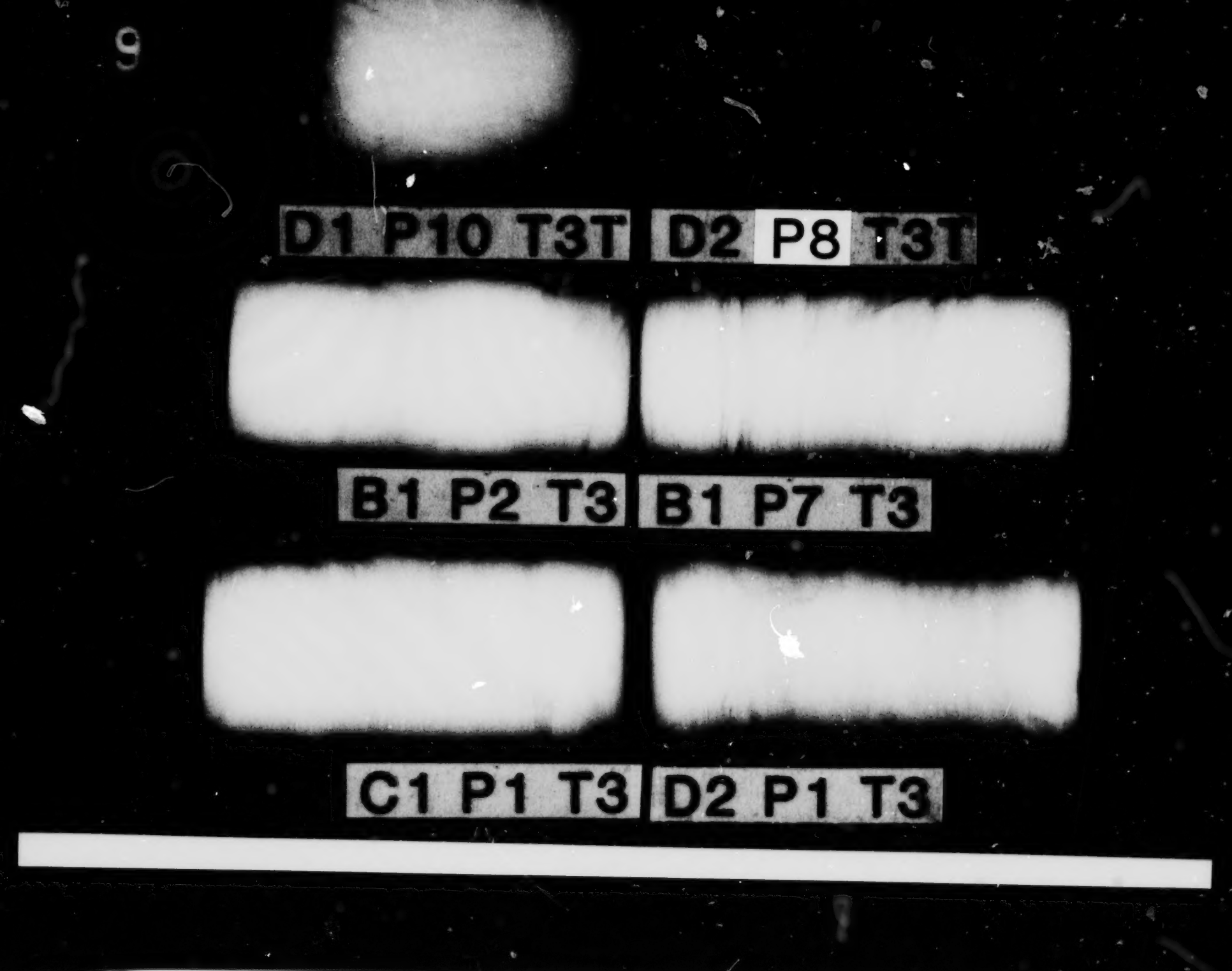

B2 P1 T2
D1 P9 T2
C3 P3 T2


B1 P4 T3
B2 P3 T3
B2 P1 T3
D1 P7 T3
D2 P4 T3
C1 P2 T3


B1 P8 T3
B2 P7 T3
C1 P4 T3


C3 P2 T3
D1 P7 T3B
D2 P4 T3B
D1 P7 T3
D2 P4 T3


D1 P3 T3
D1 P3 T3
D2 P8 T3B
D2 P8 T3
D1 P10 T3


D1 P10 T3T
D2 P8 T3T
B1 P2 T3
B1 P7 T3
C1 P1 T3
D2 P1 T3

Photography

PETRO-CANADA INC.

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

SELECTED SAMPLES FROM PRESERVRED CORE

X-RADIOGRAPHY AT 45°

1990 10 30

52135-90-3559

CORE
LABORATORIES

WELL IDENTIFICATION SHEET

150 cm
80Kv
8.45Ma
3.00 mins.

Oct 26, 1990

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 1

B1 P4 T1	B1 P4 T1 (After Leak)	(Group 1-1)
B1 P8 T1	B2 B7 T1	(Group 1-2)

Page 2

B2 P3 T1	B2 P1 T1	(Group 2-1)
C1 P2 T1	C3 P2 T1	(Group 2-1)
C1 P4 T1	D2 P6 T1	(Group 2-2)

Page 3

C3 P3 T1		(Group 3-1)

Page 4

B2 P1 T2 (1/2 sample)		(Group 5-1)
D1 P9 T2B (Portion of sample too friable to X-ray all angles)		(Group 5-2)
C3 P3 T2		(Group 6-1)

Page 5

B1 P4 T3 (1/2 sample)	B2 P3 T3 (split sample)	(Group 7-1)
B2 P1 T3 (split sample)	D1 P7 T3	(Group 7-1)
D2 P4 T3	C1 P2 T3	(Group 7-1)

Page 6

B1 P8 T3		(Group 7-2)
B2 P7 T3		(Group 7-2)
C1 P4 T3		(Group 7-2)

Page 7

C3 P2 T3		(Group 8-1)
D1 P7 T3B	D2 P4 T3B	(Group 9-1)
D1 P7 T3	D2 P4 T3	(Group 10-1)

CORE
LABORATORIES

WELL IDENTIFICATION SHEET

Oct 26, 1990

150 cm
80Kv
8.45Ma
3.00 mins.

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 8

D1 P3 T3(1.0m)	D1 P3 T3(0.20m)	(Group 11)
D2 P8 T3B	D2 P8 T3	(Group 12-1)
D1 P10 T3		(Group 12-1)

Page 9

D1 P10 T3T	D2 P8 T3T	(Group 12-2)
B1 P2 T3	B1 P7 T3	(Group 13)
C1 P1 T3	D2 P1 T3	(Group 13)

Ken Turner
Photo Technician

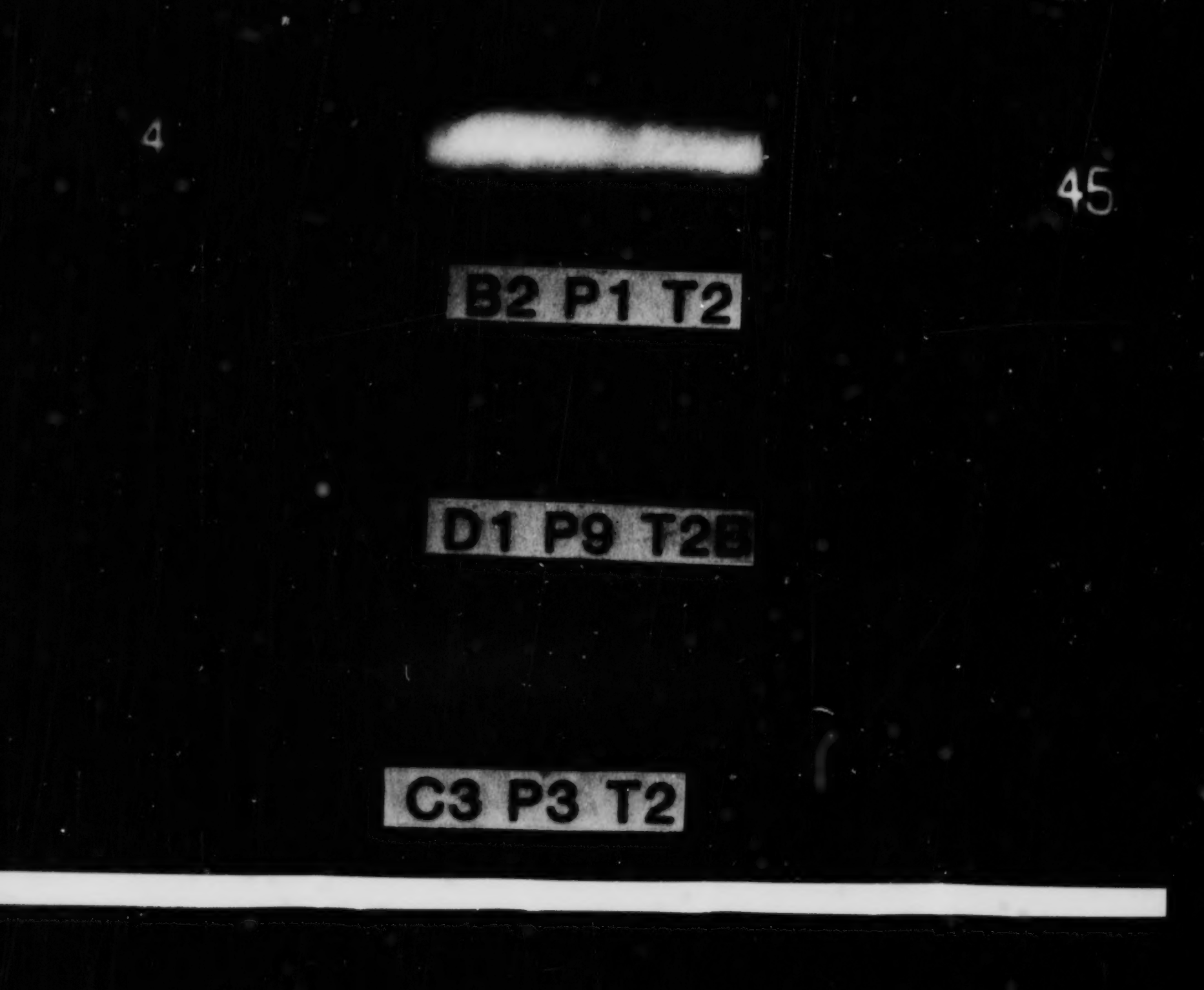
Charles Savoie
Supervisor Geological Sciences
X-Radiography/Imaging

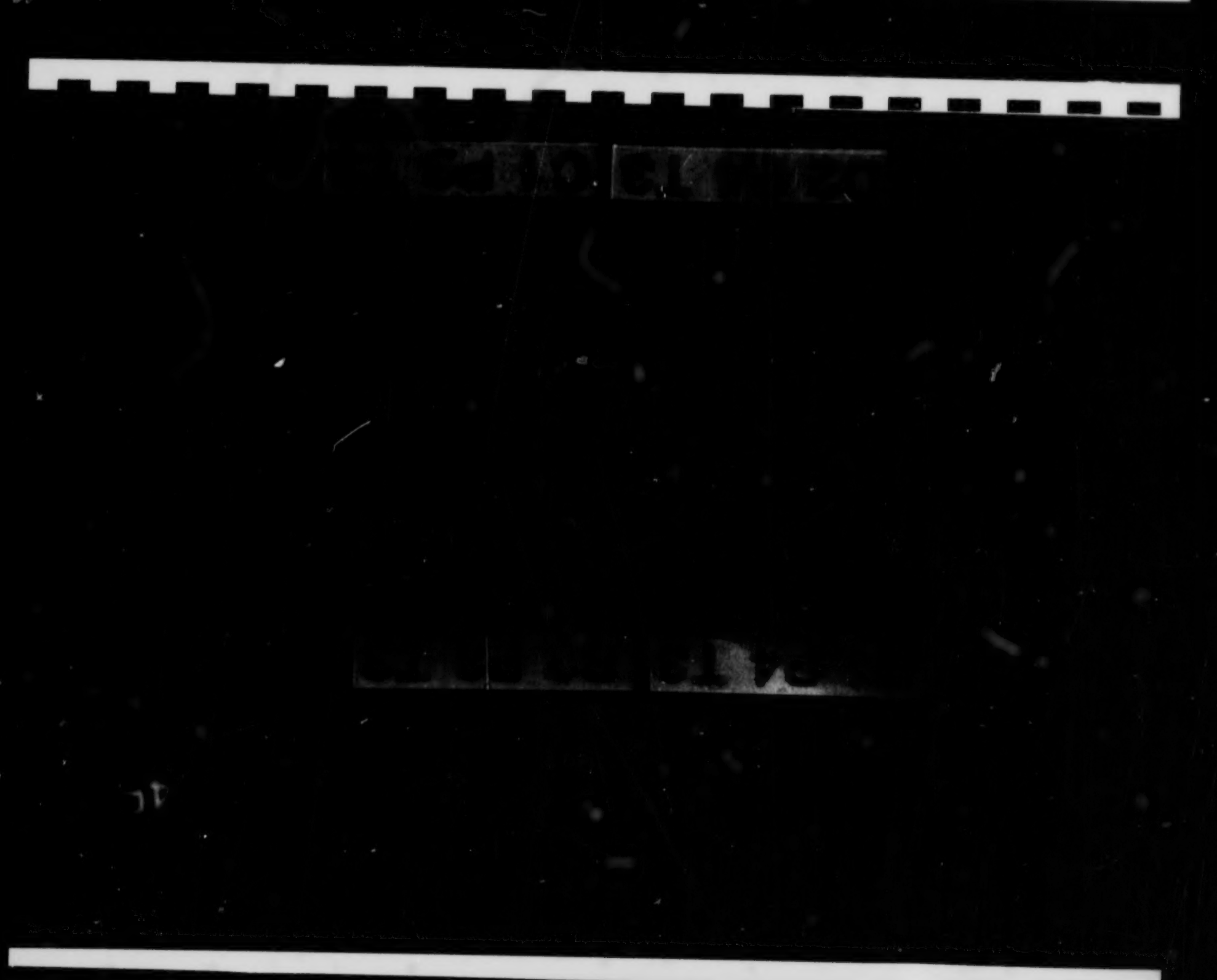
B1 P4 T1
B1 P4 T1

B1 P8 T1
B2 P7 T1

2
45
B2 P3 T1
B2 P1 T1
C1 P2 T1
C3 P2 T1
C1 P4 T1
D2 P6 T1
20

C3 P3 T1


4
45
B2 P1 T2
D1 P9 T2
C3 P3 T2



B1 P8 T3

[redacted]

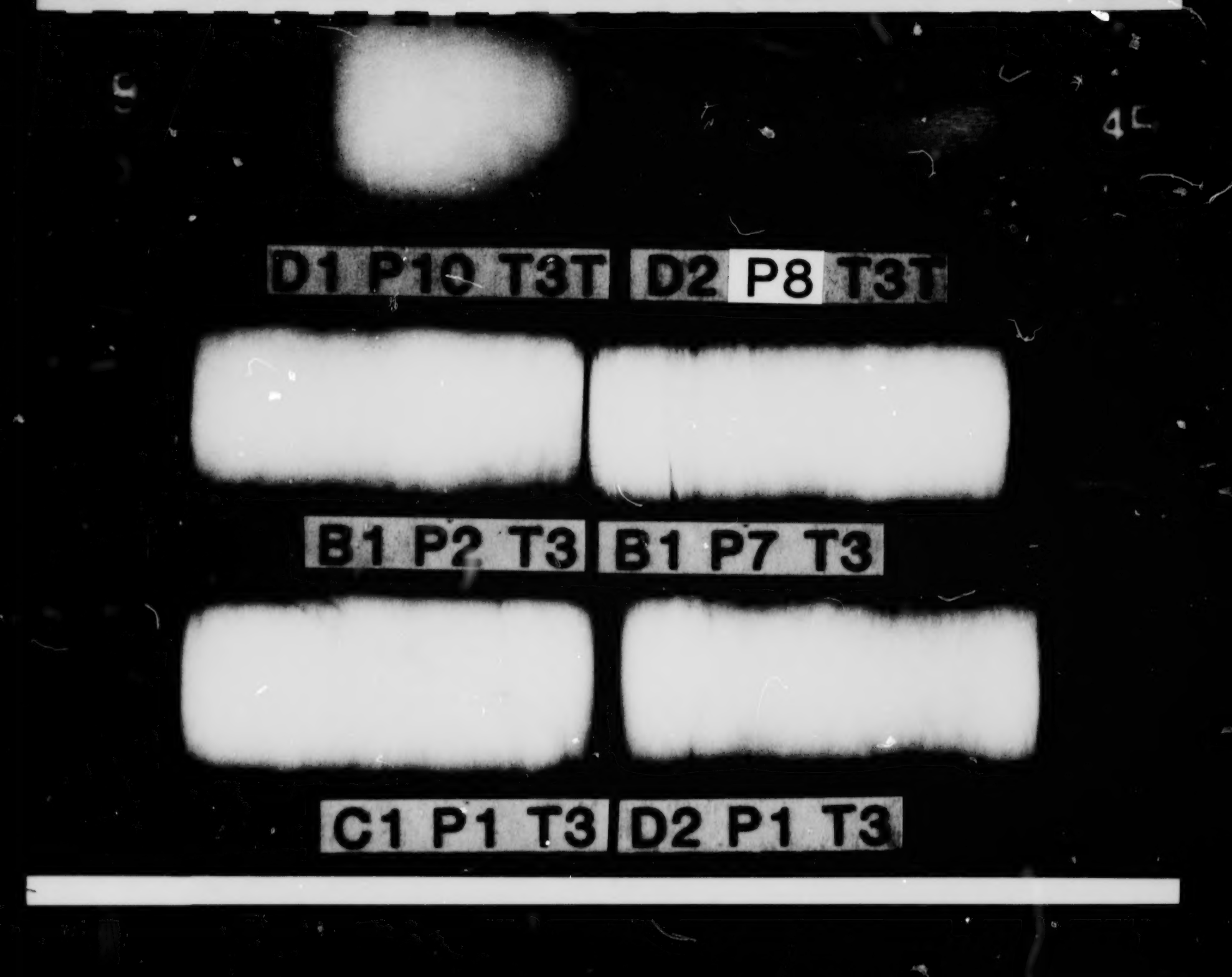
B2 P7 T3

C1 P4 T3

C3 P2 T3

D1 P7 T3B D2 P4 T3B

D1 P7 T3 D2 P4 T3


D1 P10 T3T
D2 P8 T3T
B1 P2 T3
B1 P7 T3
C1 P1 T3
D2 P1 T3

Photography

PETRO-CANADA INC.

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

SELECTED SAMPLES FROM PRESERVRED CORE

X-RADIOGRAPHY AT 90·

1990 10 30

52135-90-3559

CORE LABORATORIES

WELL IDENTIFICATION SHEET

150 cm
80Kv
8.45Ma
3.00 mins.

Oct 26, 1990

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 1			
	B1 P4 T1	B1 P4 T1 (After Leak)	(Group 1-1)
	B1 P8 T1	B2 B7 T1	(Group 1-2)
Page 2			
	B2 P3 T1	B2 P1 T1	(Group 2-1)
	C1 P2 T1	C3 P2 T1	(Group 2-1)
	C1 P4 T1	D2 P6 T1	(Group 2-2)
Page 3			
	C3 P3 T1		(Group 3-1)
Page 4			
	B2 P1 T2 (1/2 sample)		(Group 5-1)
	D1 P9 T2B (Portion of sample too friable to X-ray all angles)		(Group 5-2)
	C3 P3 T2		(Group 6-1)
Page 5			
	B1 P4 T3 (1/2 sample)	B2 P3 T3 (split sample)	(Group 7-1)
	B2 P1 T3 (split sample)	D1 P7 T3	(Group 7-1)
	D2 P4 T3	C1 P2 T3	(Group 7-1)
Page 6			
	B1 P8 T3		(Group 7-2)
	B2 P7 T3		(Group 7-2)
	C1 P4 T3		(Group 7-2)
Page 7			
	C3 P2 T3		(Group 8-1)
	D1 P7 T3B	D2 P4 T3B	(Group 9-1)
	D1 P7 T3	D2 P4 T3	(Group 10-1)

CORE
LABORATORIES

WELL IDENTIFICATION SHEET

150 cm
80Kv
8.45Ma
3.00 mins.

Oct 26, 1990

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 8

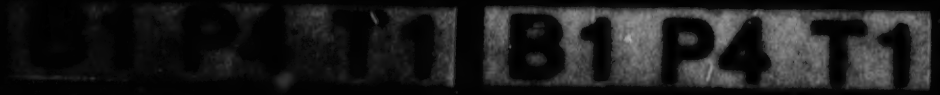
D1 P3 T3(1.0m)	D1 P3 T3(0.20m)		(Group 11)
D2 P8 T3B	D2 P8 T3		(Group 12-1)
D1 P10 T3			(Group 12-1)

Page 9

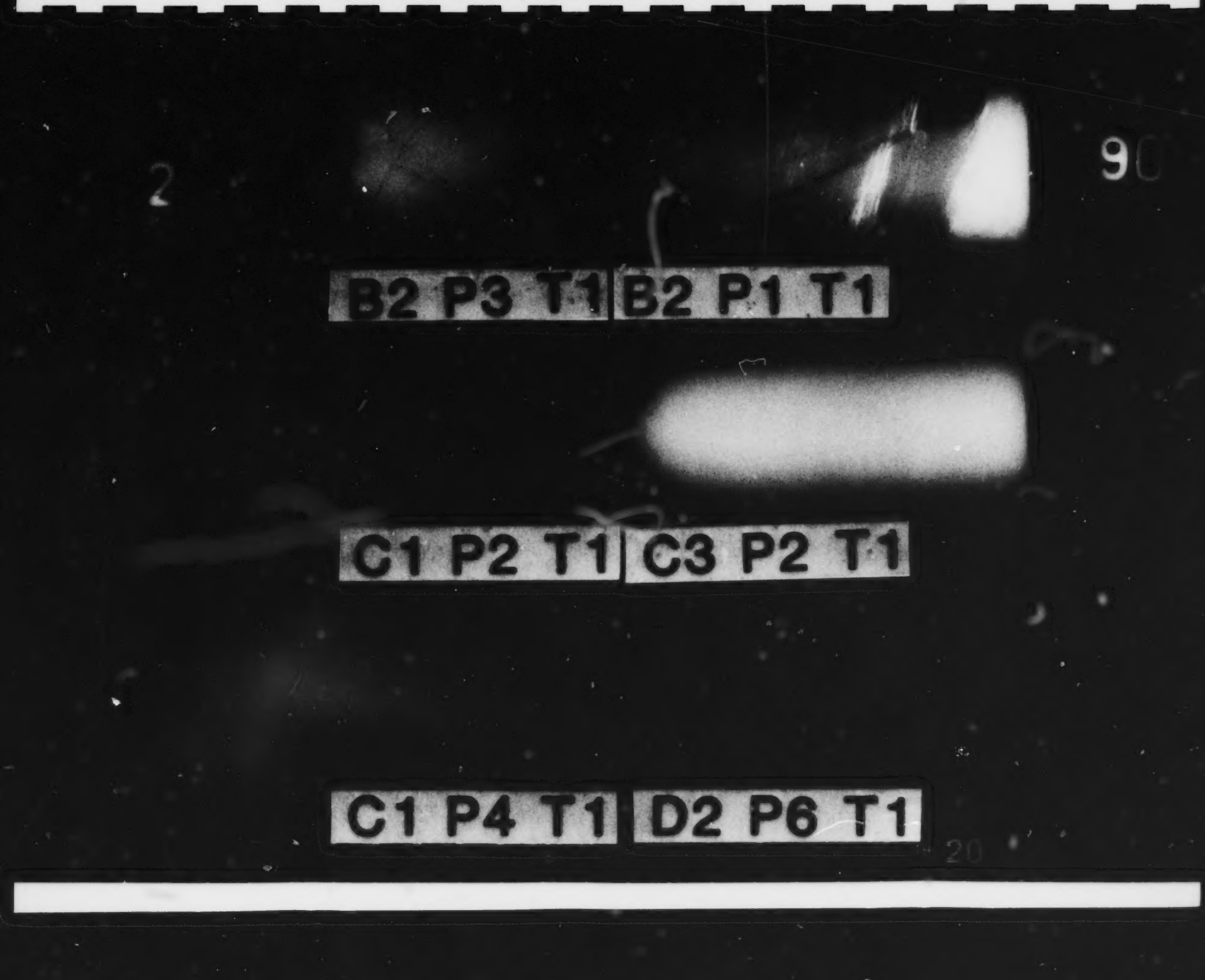
D1 P10 T3T	D2 P8 T3T	(Group 12-2)
B1 P2 T3	B1 P7 T3	(Group 13)
C1 P1 T3	D2 P1 T3	(Group 13)

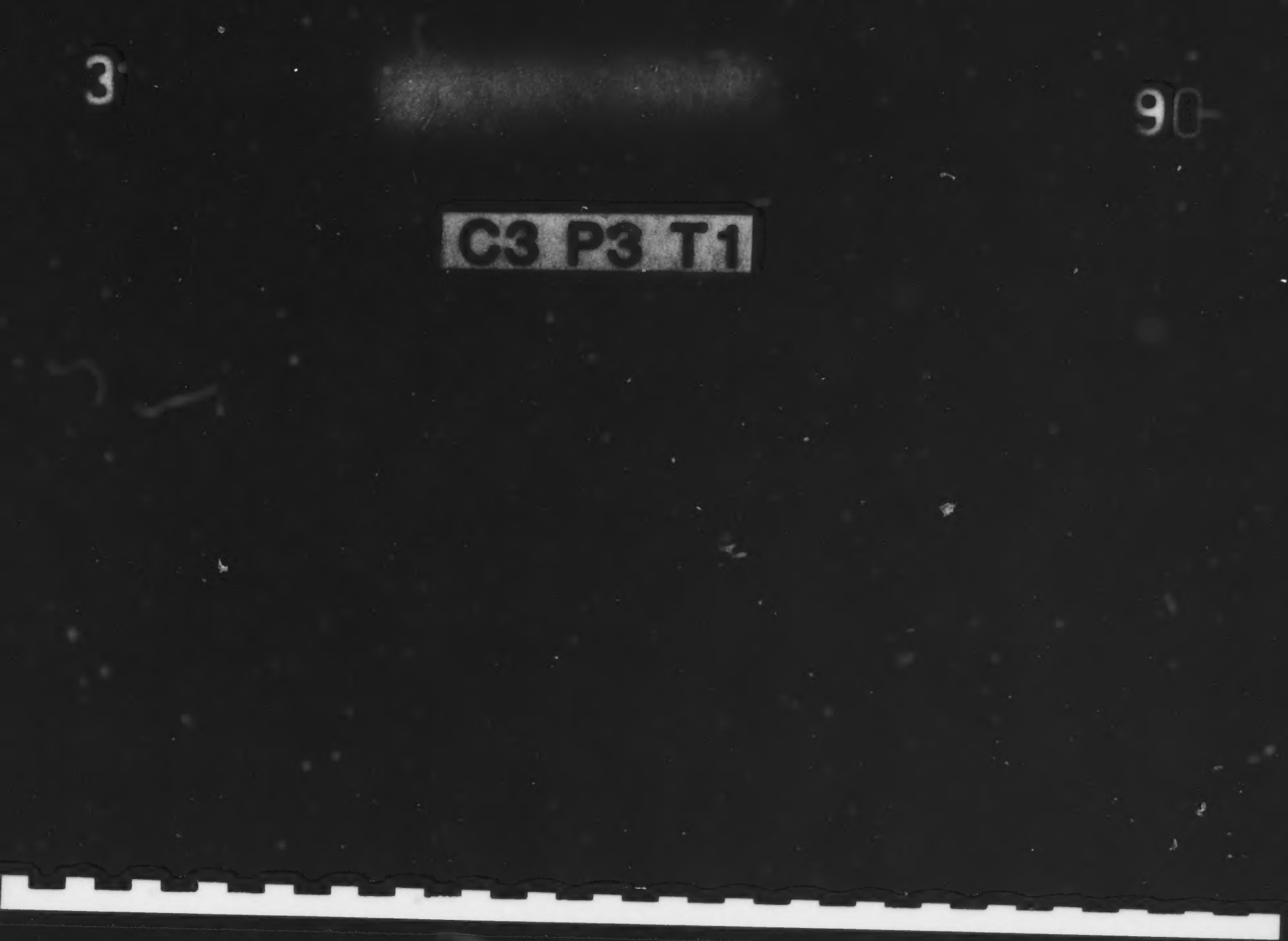
Ken Turner
Photo Technician

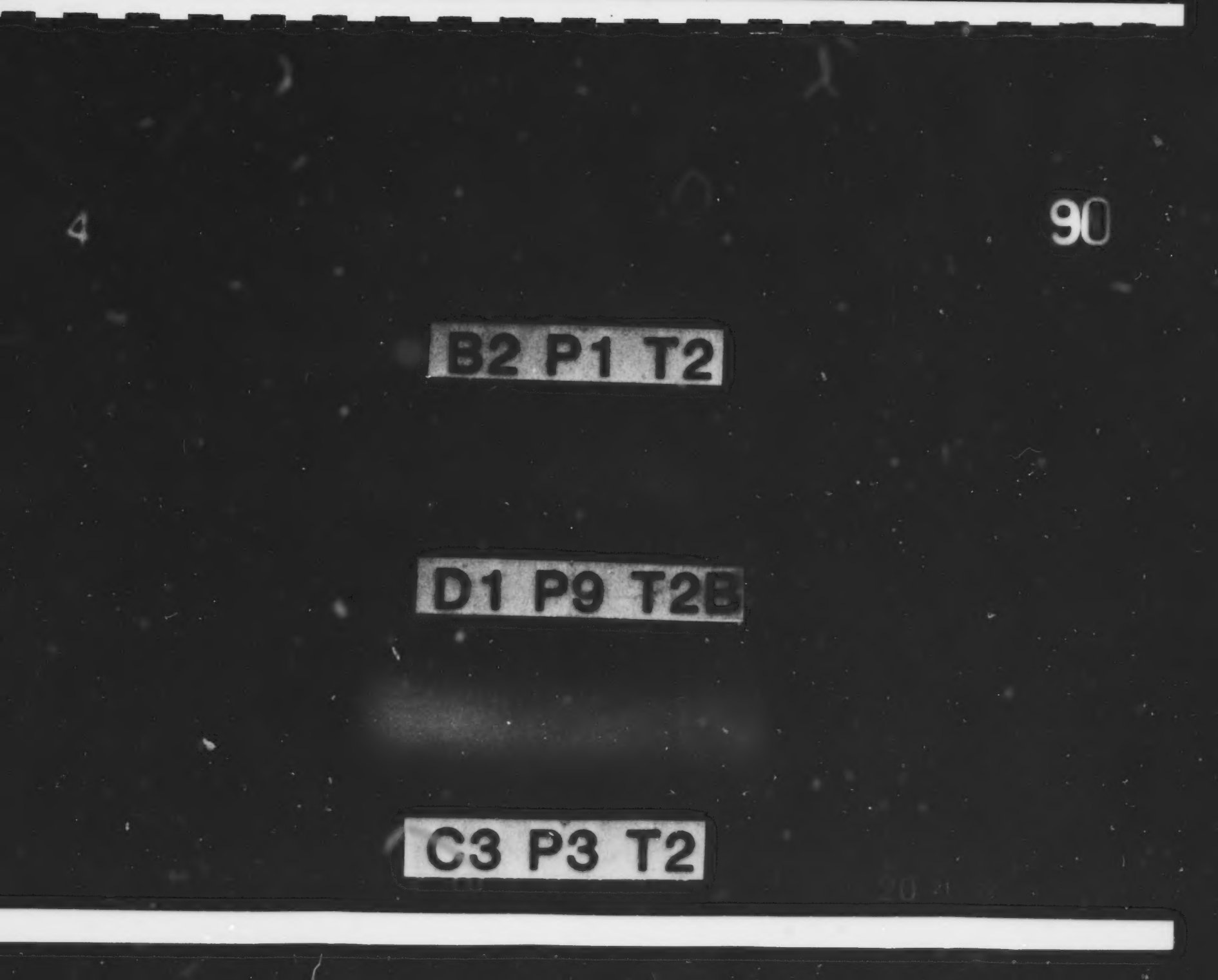
Charles Savoie
Supervisor Geological Sciences
X-Radiography/Imaging

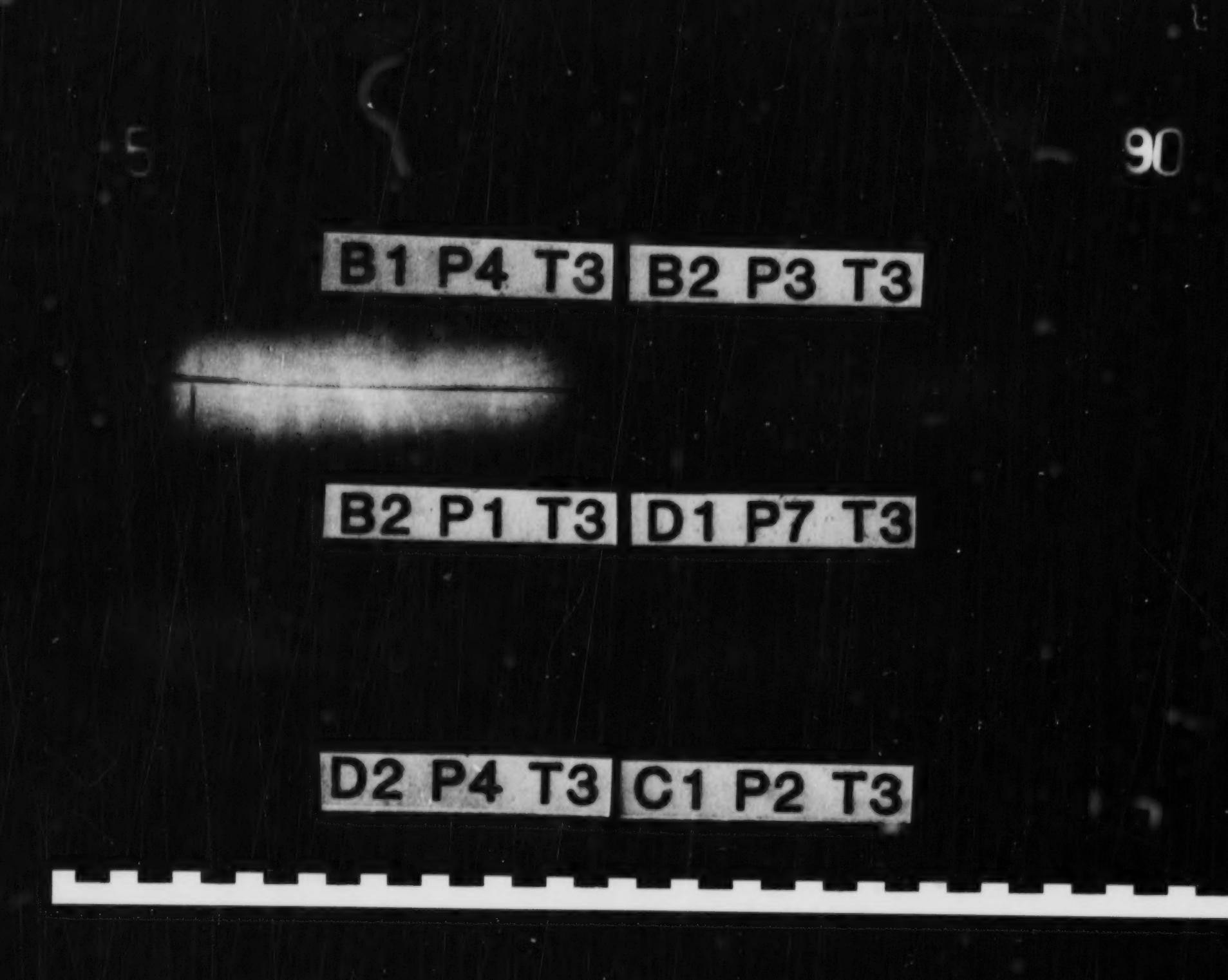

B1 P4 T1
B1 P4 T1

B1 P8 T1
B2 P7 T1


B2 P3 T1
B2 P1 T1
C1 P2 T1
C3 P2 T1
C1 P4 T1
D2 P6 T1


3
90
C3 P3 T1


4
90
B2 P1 T2
D1 P9 T2B
C3 P3 T2


B1 P4 T3
B2 P3 T3
B2 P1 T3
D1 P7 T3
D2 P4 T3
C1 P2 T3

90

B1 P8 T3

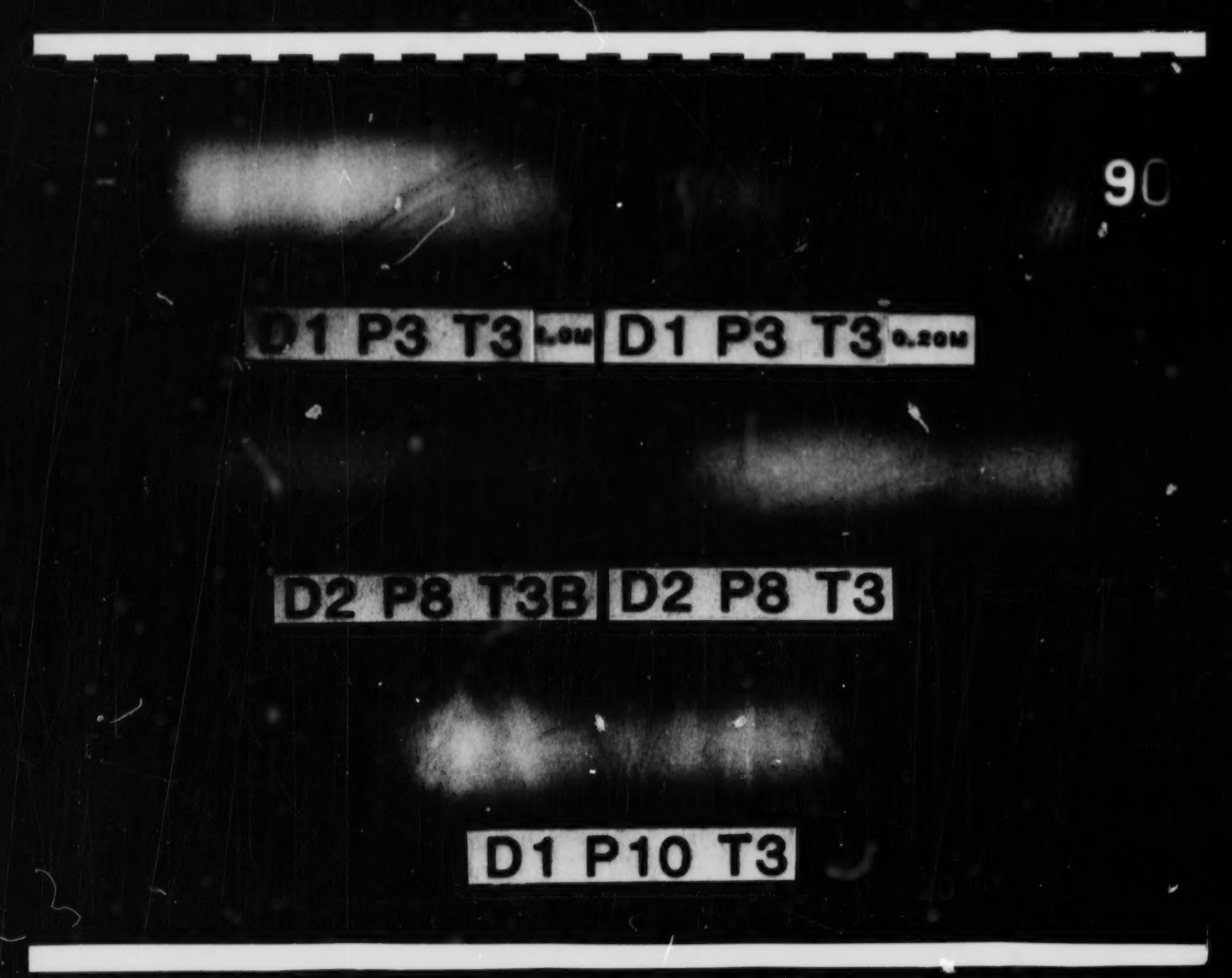
B2 P7 T3

C1 P4 T3

C3 P2 T3

D1 P7 T3B D2 P4 T3B

D1 P7 T3 D2 P4 T3


D1 P3 T3 1.0M
D1 P3 T3 0.20M
D2 P8 T3B
D2 P8 T3
D1 P10 T3

D2P1T2
D2P1T3

Photography

PETRO-CANADA INC.

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

SELECTED SAMPLES FROM PRESERVRED CORE

X-RADIOGRAPHY AT 135•

1990 10 30 52135-90-3559

CORE LABORATORIES

WELL IDENTIFICATION SHEET

Oct 26, 1990

150 cm
80Kv
8.45Ma
3.00 mins.

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 1			
	B1 P4 T1	B1 P4 T1 (After Leak)	(Group 1-1)
	B1 P8 T1	B2 B7 T1	(Group 1-2)
Page 2			
	B2 P3 T1	B2 P1 T1	(Group 2-1)
	C1 P2 T1	C3 P2 T1	(Group 2-1)
	C1 P4 T1	D2 P6 T1	(Group 2-2)
Page 3			
	C3 P3 T1		(Group 3-1)
Page 4			
	B2 P1 T2 (1/2 sample)		(Group 5-1)
	D1 P9 T2B (Portion of sample too friable to X-ray all angles)		(Group 5-2)
	C3 P3 T2		(Group 6-1)
Page 5			
	B1 P4 T3 (1/2 sample)	B2 P3 T3 (split sample)	(Group 7-1)
	B2 P1 T3 (split sample)	D1 P7 T3	(Group 7-1)
	D2 P4 T3	C1 P2 T3	(Group 7-1)
Page 6			
	B1 P8 T3		(Group 7-2)
	B2 P7 T3		(Group 7-2)
	C1 P4 T3		(Group 7-2)
Page 7			
	C3 P2 T3		(Group 8-1)
	D1 P7 T3B	D2 P4 T3B	(Group 9-1)
	D1 P7 T3	D2 P4 T3	(Group 10-1)

CORE
LABORATORIES

WELL IDENTIFICATION SHEET

Oct 26, 1990

150 cm
80Kv
8.45Ma
3.00 mins.

PCI PCEJ HANGINGSTONE 16-27 VARIOUS WELLS

PROJECT NUMBER: 52135-90-3559

X-RADIOGRAPHY OF EACH SAMPLE AT 0°, 45°, 90°, AND 135°

Page 8

D1 P3 T3(1.0m)	D1 P3 T3(0.20m)	(Group 11)
D2 P8 T3B	D2 P8 T3	(Group 12-1)
D1 P10 T3		(Group 12-1)

Page 9

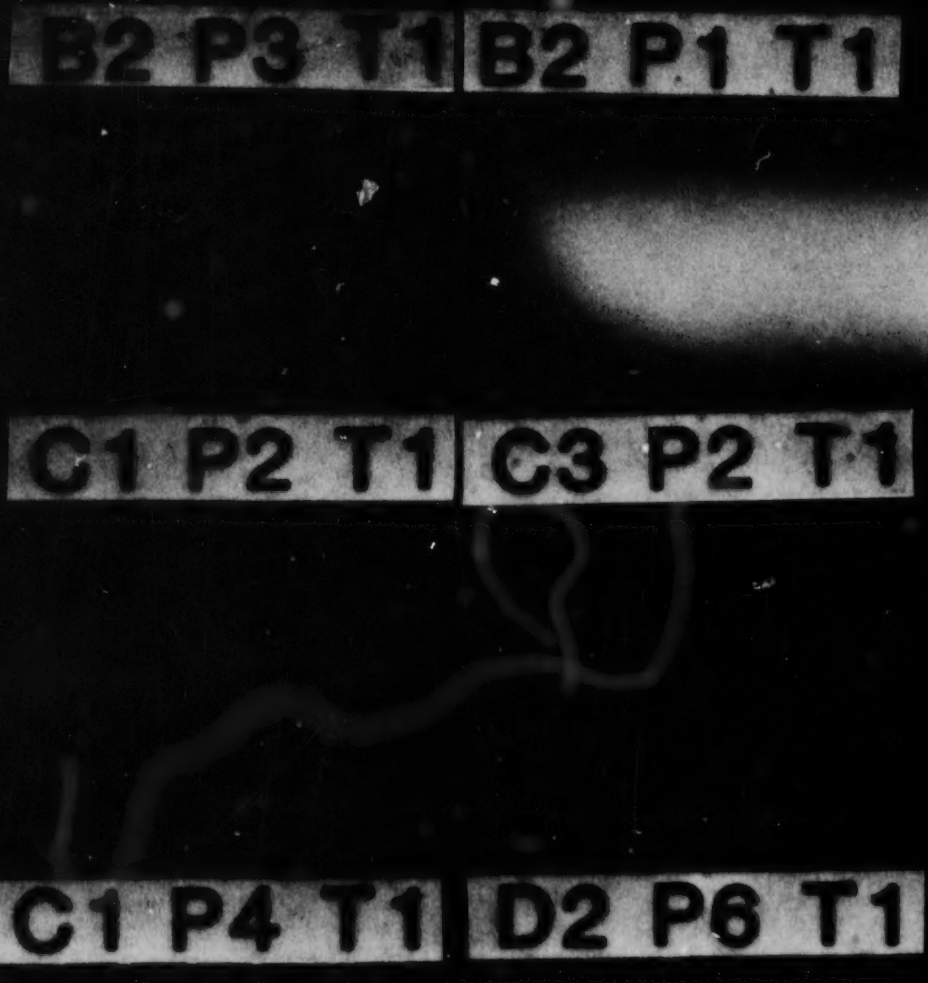
D1 P10 T3T	D2 P8 T3T	(Group 12-2)
B1 P2 T3	B1 P7 T3	(Group 13)
C1 P1 T3	D2 P1 T3	(Group 13)

Ken Turner
Photo Technician

Charles Savoie
Supervisor Geological Sciences
X-Radiography/Imaging

B1 P4 T1 B1 P4 T1

B1 P8 T1 B2 P7 T1

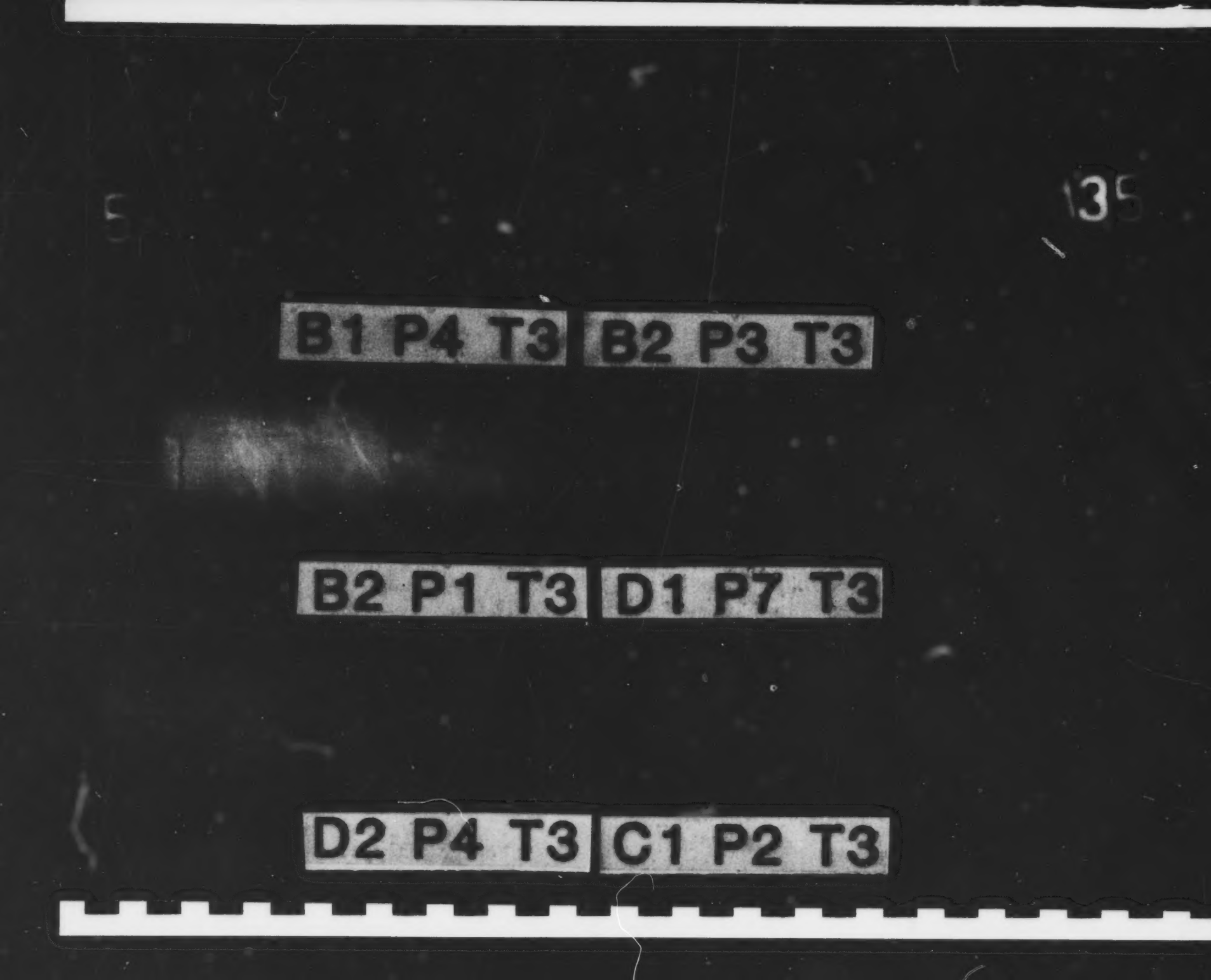

B2 P3 T1
B2 P1 T1
C1 P2 T1
C3 P2 T1
C1 P4 T1
D2 P6 T1

C3 P3 T1

B2 P1 T2

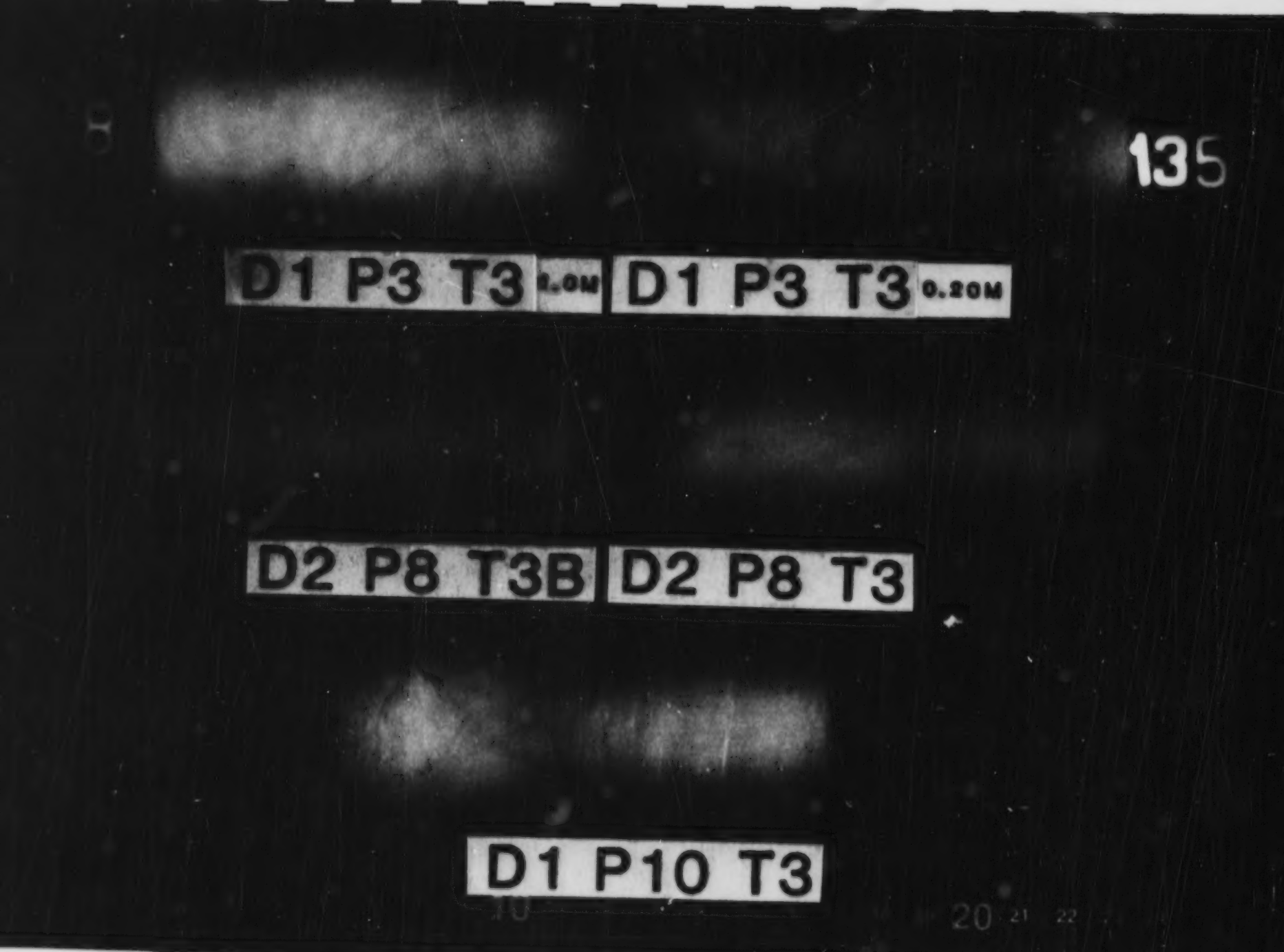
D1 P9 T2B

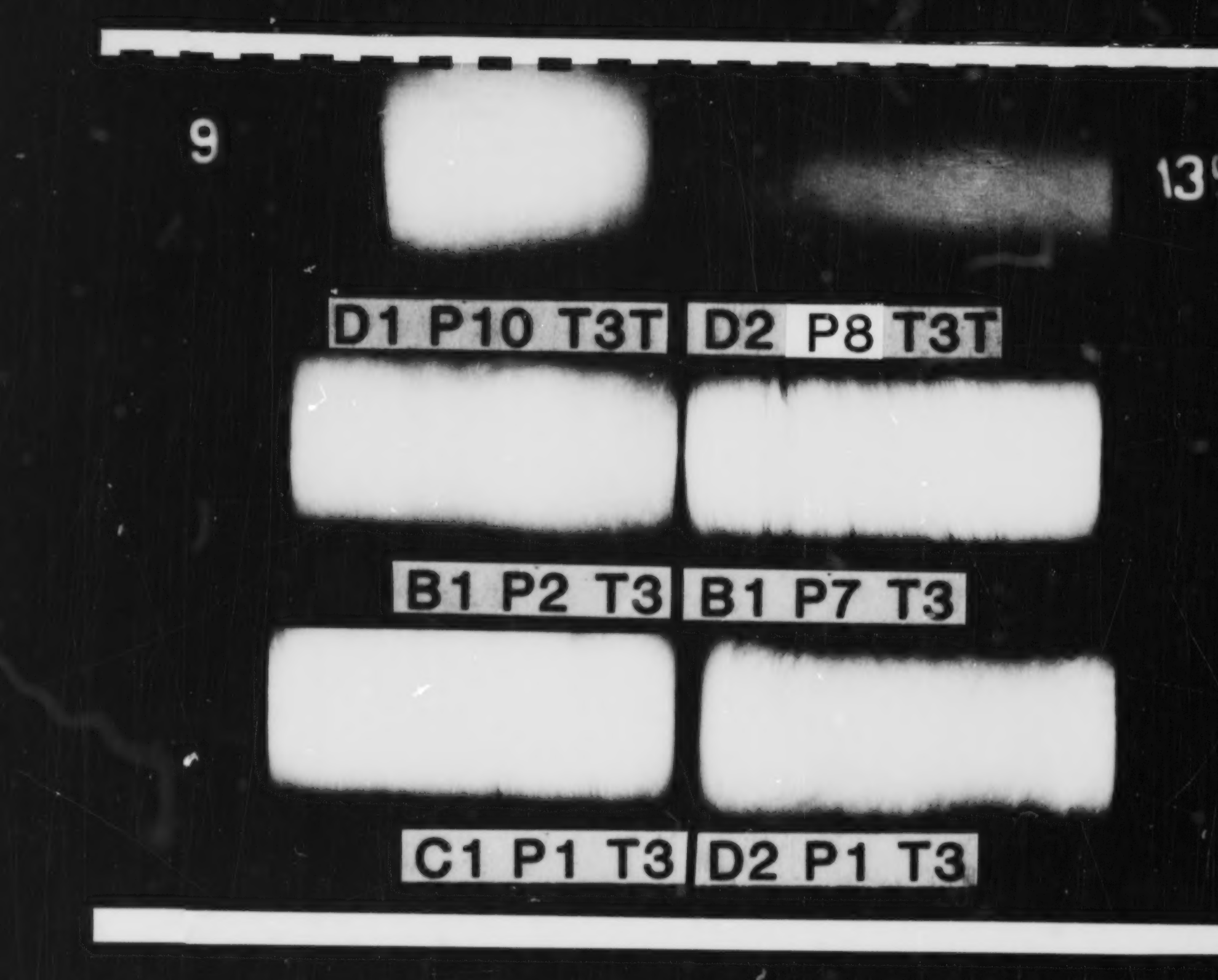
C3 P3 T2


B1 P4 T3
B2 P3 T3
B2 P1 T3
D1 P7 T3
D2 P4 T3
C1 P2 T3

B1 P8 T3
B2 P7 T3
C1 P4 T3

C3 P2 T3
D1 P7 T3B
D2 P4 T3B
D1 P7 T3
D2 P4 T3


D1 P3 T3 1.0M
D1 P3 T3 0.20M
D2 P8 T3B
D2 P8 T3
D1 P10 T3


9
13
D1 P10 T3T
D2 P8 T3T
B1 P2 T3
B1 P7 T3
C1 P1 T3
D2 P1 T3

GEOMECHANICAL SIMULATION OF TAR SANDS AND ITS APPLICATION TO RESERVOIR SIMULATION

SIMTECH CONSULTING SERVICES

GEOMECHANICAL SIMULATION OF TAR SANDS

AND ITS APPLICATION TO RESERVOIR SIMULATION

FINAL REPORT

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1. Introduction

The engineering design of the PCEJ project requires a realistic estimate of the dimensions of the fractures created in the injection cycles. PetroCanada is using a combination of SIMTECH's TARSIM software and reservoir simulators for predicting fracture growth and production performance.

One of the critical parameters appears to be the amount of oil sand dilation which will take place in the failure region around the fracture. In the TARSIM models, the dilation is specified as an input parameter (typically 1 - 4 %). Because it was not clear how the dilation obtained in the laboratory should be related to the value needed for the simulators, PetroCanada initiated a combined laboratory and simulation study to estimate more accurately the compressibility and dilation values which should be used in field simulation work.

This report describes the numerical study of the geomechanical behaviour of the of oil sand and the recommended approach to modeling dilation in the reservoir simulation of the PCEJ project. All work was done using the ENHANS 2-D geomechanical model. Because of the budget constraints, this study should be regarded as preliminary. Some recommendations for further work are found in Section 6.

2. Scope of the Work

As detailed in SIMTECH's proposal, dated May 9, 1990, the initial scope of the work consisted of two major tasks:

1) Simulate the laboratory tests to tune the constitutive model to the data. Initially, it was assumed that only one test (considered to be the most representative) will be matched. In the course of the work, it was found necessary to include a wide range conditions and three tests were actually matched.

2) Simulate a typical injection well in the PCEJ project. It was assumed that a horizontal fracture is created and the problem was solved in x-z cylindrical coordinates.

The results of the second task were unexpected because they indicated a small amount of dilation compared to the lab experiments. This was attributed to the difference in the stress paths. In order to verify this conclusion, the following task was added:

3) Simulate a hypothetical lab test which would have a similar stress path to what was computed for a typical element of oil sand around the fracture and compare the dilation predicted from such lab test to the field simulation.

The following Sections describe briefly the technical approach and results of the work. After the completion of the Draft Report, some enhancements were made to the ENHANS model used for this study. They resulted in improved numerical stability and reduced computer time. Consequently, all results shown her were re-generated with the new model and are different (and more accurate) than those in the Draft Report.

3. Task-1 History Match of The Laboratory Core Test

The primary purpose of this task was to tune the input data of the constitutive model in ENHANS to the results obtained from the laboratory experiments. Ideally one wants to find a set of parameters which would match the lab data in a wide range of stresses. As described in the proposal, only one history match for a specified core was originally planned. However, it was found that many parameters which characterize the core properties can not be defined with only one history match. In other words, in order to define the following parameters, it is necessary to have several simulation results for various effective stress levels.

The generalized hyperbolic model

During the history matching process, we found that it was necessary to modify some of the empirical correlations currently used in the constitutive model because the standard hyperbolic model was not capable of matching the data. Success in tuning the model was achieved by changing the formulation as follows:

The standard hyperbolic model defines modulus as (e.g., Refs.1,2):

$$E = E_i[1 - R_f(\frac{\Delta\sigma_d}{(\Delta\sigma_d)_f})]^2$$

where

$$E_i = k_e\ P_a\ (\sigma_3'/P_a)^{n_e}$$

is the initial modulus and $\Delta\sigma_d$ and $(\Delta\sigma_d)_f$ are the deviatoric stress at the given point and the corresponding stress at failure. The form of the multiplying term on E_i controls the shape of the stress-strain curve. To provide more flexibility, it was generalized as follows:

$$E = E_i[1 - (R_f\frac{\Delta\sigma_d}{(\Delta\sigma_d)_f})^{e2}]^{e1}$$

where $e1$ and $e2$ are arbitrary exponents. The classical model is obtained by setting $e1 = 2, e2 = 1$.

The treatment of dilation is according to the method of Ref. 3. It was found necessary to generalize the method by allowing the onset of dilation to be at variable friction angle

$$\Phi_{cv} + \Phi_{cv}'\ \sigma_3'$$

instead of a constant value Φ_{cv} (constant volume friction angle).

The matching process

With the above generalized model, excellent matches of data were obtained by setting $e1 = 1$ and $e2 = 2$. The other parameters which define the constitutive model are:

k_e ... elastic modulus constant for the hyperbolic model
n_e ... elastic modulus exponent for the hyperbolic model
k_b ... bulk modulus constant for the hyperbolic model
n_b ... bulk modulus exponent for the hyperbolic model
Φ ... friction angle at a unit normalized stress (degree)
$\delta\Phi$ ... change in friction angle for 10 times increase in the normalized stress
Φ_{max} ... maximum friction angle (upper limit)

During the history match of three cores, n_e and n_b were arbitrarily selected and used. Thus, the elastic modulus and bulk modulus are controled by k_e and k_b respectively. The numbers to specify the friction angle correlation to the effective stress, Φ and $\delta\Phi$, were selected such that the the friction angle for the given effective stress was limited by the maximum friction angle (Φ_{max}).

The numbers used in three separate history matches are listed in Table 1. The last column of the table is the correlated values with which all three cores can be characterized. The procedure to obtain the correlated values is:

1) Calculate the initial Young's moduli from the values used in each history match run with the following equation.

$$E_i = k_e * P_a * (\sigma_3'/P_a)^{n_e}$$

where :

E_i ... initial Young's modulus
P_a ... atmospheric pressure (101.33 kPa)
σ_3' ... effective stress (200, 500 or 1000 kPa)

2) Plot E_i and (σ_3'/P_a) on log-log paper. The value of intersect at $(\sigma_3'/P_a) = 1.0$ is the product $k_e * P_a$ and the slope is n_e. Figure 1 shows the result of this plot.

3) Calculate the bulk moduli from the parameters used in each history match run with the following equation.

$$B_m = k_b * P_a * (\sigma_3'/P_a)^{n_b}$$

where :
B_m ... bulk modulus of the soil matrix

4) Plot B_m and (σ_3'/P_a) on log-log paper. The value of intersect at $(\sigma_3'/P_a) = 1.0$ is the product $k_b * P_a$ and the slope is n_b. The result of this plot is shown in Figure 2.

5) Plot Φ_{max} and (σ_3'/P_a) on semi log paper. The value of intersect at $(\sigma_3'/P_a) = 1.0$ is Φ and the slope is $\delta\Phi$, which is shown in Figure 3.

The calculated deviator stress and axial strain relationship with the history match parameters and the correlated parameters, along with the laboratory measurements for the three cores are shown in Figs. 4, 6 and 8. The results of the volumetric strain vs. axial strain for these three cores are shown in Figs. 5, 7 and 9. The match of the correlated model with laboratory data is excellent.

In the laboratory experiments, the samples were loaded beyond the failure and the post-peak deformation behaviour was measured. Currently, the hyperbolic model can not handle the post-peak deformation behaviour. Besides, there are many arguments as to whether or not this post-peak deformation represents in-situ sand behaviour in the field. Thus, a match of the post-peak behaviour was not tried, in accordance with our proposal.

4. Task-2 Simulation of a Horizontal Fracture

The major objective of this task was to determine the amount of volumetric strain expected in the reservoir around a fracture with the geomechanical property data of the oil sand obtained in Task-1. To this end, a simulation of a typical injection well at the PCEJ project area was conducted with the ENHANS model.

It was assumed that a horizontal fracture was created in the center of the formation. Fig. 10 shows a schematic view of the study area. A cylindrical coordinate with a horizontal fracture of an 80 meter radius was applied. The fracture radius was fixed during the entire injection period (ie., the fracture growth aspect was not included). A finite element mesh used in the reservoir simulation study is shown in Fig. 11. Hand written numbers in the middle of the mesh are the element numbers and hand written numbers at the corner of the mesh are the node numbers. The data for the simulation is shown in Table 2, and corresponds to initial stress state with all stresses equal.

It was found that the stress paths during the loading of stresses at the fracture are quite different from those of the laboratory experiments and are also dependent on the distance from the fracture. Two stress paths from two different locations are plotted in Fig. 12. Grid blocks adjacent to the fracture; blocks 11, 12, 31 and 32, take the path represented by the circle and grid blocks relatively remote from the horizontal fracture; blocks 17, 18, 37 and 38, take the path noted by the cross mark. This difference in stress paths creates a difference in the change in vertical strain, volumetric strain, the amount of dilation and all of the other calculation results. Therefore, the change in volumetric and vertical strains are separately plotted for these two locations.

In order to analyze the volumetric dilation caused by shear failure, a case with no dilation where shear failure is not included in the computation was first run. In this case, dilation is not computed and stresses are allowed to exceed the failure envelope. Results of strain changes for this case are shown in Figs. 13 to 16. The vertical and volumetric strain at grid blocks adjacent to fracture are shown in Figs. 13 and 14 respectively. The vertical strain reached maximum at an early injection time and then gradually declined indicating that gradual shrinking occurred later on. The volumetric strain was about 2.5 % at the beginning of the process and slowly increased to about 2.8 % at the end.

The vertical and volumetric strains at grid blocks relatively remote from the horizontal fracture are shown in Figs. 15 and 16 respectively. At the beginning of the process, the vertical strains became negative at these blocks and then increased gradually. The volumetric strains gradually increased over the entire injection period and reached an average value of 3.2 % at the end of injection.

The results of strain changes with shear failure are shown in Figs. 17 to 20. The vertical and volumetric strains at grid blocks adjacent to fracture are shown in Figs. 17 and 18 respectively. The difference in vertical strain changes between Fig. 17 and Fig. 13 is caused by stress re-distribution after failure and by invoking the dilation. Leaps in the vertical strain at blocks 11 and 13 after 30 days of injection are caused by shear failure.

The amount of vertical strain at these blocks exceeded the amount of volumetric strain (which is shown in Fig. 18) when the blocks were failed. Physically, this indicates that these blocks exhibited compresion rather than expansion in the horizontal direction when these blocks reached the failure condition. The average volumetric strain of these blocks is about 3.1 %.

The vertical and volumetric strains at grid blocks remote from the fracture are shown in Figs. 19 and 20 respectively. The development of vertical strain is smooth during injection. The average volumetric strain for these blocks at the end of injection is about 3.-3.5 %.

Summary of results

The volumetric behaviour for the above conditions can be summarized as follows:

- the volumetric strain, without considering the shear dilation, is about 3.0 % (2.8 % for blocks 11, 12, 31 and 32, and 3.2 % for blocks 17, 18, 37 and 38)
- the volumetric strain, considering the shear dilation, is about 3.3 % (3.1 % for blocks 11, 12, 31 and 32, and 3.5 % for blocks 17, 18, 37 and 38)
- the bulk compressibility to be used in a reservoir simulation study is $0.03/(P_{fracture} - P_{initial}) = 0.03/(8121\text{-}1921) = 0.000004838\ kPa^{-1}$
- the rock compressibility to be used in a reservoir simulation study is $(0.000004838 - C_s(1.0+\phi))/\phi = 0.000004838/0.393 = 0.00001231\ kPa^{-1}$.
- the value of dilatant strain to be used in reservoir simulation is about 0.3 %. This value should be used as an input in the CONS, TARFRAC and TSAND models.

These results indicate that the shear dilation mechanism accounts only for a small portion of the total oil sand volume increase. Majority of the volumetric strain is caused by unloading of the oil sand to very small effective stress. This is somewhat surprising and indicates that the large dilation measured in the lab experiments is not necessarily achieved in the field.

Fig. 21 shows the extension of the failure by mapping the blocks which failed at the end of 40 days of injection. It shows that the growth of failure does not extend to all the blocks in perpendicular direction from the loading zone which is the fracture face. This irregularity may be created by numerical effects associated with stress re-distribution after failure and if so, it could be probably reduced by finer grid and smaller time steps (this was not tried due to budget constraints). However, it is also possible that the re-consolidation has taken place in some areas due to stress re-distribution. This aspect would require more careful study. Regardless of these details, there is a clear difference in the behaviour between blocks near the edge of the fracture (blocks 31 to 40) and other blocks facing the fracture (blocks 1 to 30).

Fig. 22 shows the movement at the top of the formation when the shear dilation was not considered. About 24 cm of formation lift was computed for the study area. Since a half of the formation was simulated in this study, the actual lift under this condition

was 48 cm. About 1 cm of small formation subsidence was predicted at the early period of injection at the area beyond the fracture.

The movement at the top of the formation when the shear dilation was considered is shown in Fig 23. Largest movement was calculated at about 35 meters from the well. (In the Draft report, the result shown has an anomalous peak at 50 m which was caused by numerical effects.) The average movement at the top of the formation in the horizontal fracture area will be about 30 cm.

5. Task-3 Simulation of a Hypothetical Core Test

After the results of Task-2 were examined, the simulation study was extended to try to simulate some hypothetical laboratory cases which have similar stress paths to those found in the reservoir simulation study. The purpose of this work was to check whether the calculated volumetric strain in the reservoir model can be reproduced in a laboratory model.

It is possible to create many different stress paths for laboratory core tests. Hypothetically one can create any stress path desired by manipulating the boundary conditions of fluid pressure, axial stress and confining stress.

Two hypothetical laboratory test cases were modelled here. A schematic of their boundary conditions is shown in Fig. 24. The stress paths resulting from these tests are shown in Fig. 25. Test -1 has a stress path similar to the path in grid blocks near the fracture such as in grid blocks 11, 12, 31 and 32. Test -2 has a stress path similar to that of grids 17, 18, 37 and 38.

The calculated volumetric dilations for these two tests with and without volumetric dilation are:

	Test - 1	Test - 2
No dilation	2.60 %	3.30 %
With dilation	3.27 %	3.64 %

This simulation results agree well with the reservoir simulation result in the following points:

- the volumetric strain for Test -2 is higher than that for Test - 1 by about 0.3 to 0.7 %
- the volumetric strain without considering the shear dilation is about 3.0 %
- the volumetric dilation by shear failure is in the range of 0.3 to 0.7. %.

This verifies the internal consistency of the modelling and shows that the difference in the behaviour between the lab experiments and field injection are due to different stress paths.

6. Recommendations

The simulation work reported here was of a preliminary and exploratory nature due to the limited time. Several extensions can be recommended in order to answer some areas of concern and to make full utilization of the results presented in this report. The following are some of the recommendations:

1) In our study, the results of a laboratory triaxial compression test was simulated to tune the constitutive model. As described in the text, the stress path of this laboratory test and paths applied to the reservoir simulation study are quite different. Therefore, it is recommended to do history match of the laboratory test which was performed during Task-1 of the geotechnical laboratory tests, which are similar to the paths obtained from the reservoir simulation study.

2) It is understood that the minimum confining stress during the Task-1 of the laboratory experiment did not reach values lower than 500 kPa. This may be due to the difficulty in obtaining good data during the reloading period. However, the stress-strain behaviour at a low effective stress condition is important for a reservoir simulation model. Thus a laboratory experiment which will reach the lowest possible effective confining stress is recommended. When a laboratory test procedure is planned, the planned stress path should be tested with the ENHANS model before actually conducting the laboratory test.

3) The surface heave can be calculated by extending the computational mesh. One or two additional layers are recommended to include overburden rock. A different set of physical property data than those of formation should be used in the grid blocks for overburden.

4) The results presented in this study will be dependent on the initial stress state in the reservoir and the assumption about fracture orientation. The conclusions may change when initial stress conditions with some stress contrast are considered.

5) For simplicity, a fixed radius of horizontal fracture was used in the study. The fracture radius, in the field, increased during the injection period. The time dependent fracture radius can be calculated by the TARFRAC model. This time dependent boundary condition can be applied in the ENHANS model for a more accurate simulation.

6) The model was constructed so that a half of the formation is calculated, and symmetric behaviour was assumed for the remaining half of the formation. This assumption may not be accurate. Thus, it may be desirable to use a full scale of formation and overburden, and apply different boundary conditions at the upper and the lower boundary. At the stress free earth surface, constant

confining stress may be an adequate boundary condition. At the bottom, no vertical displacement may be appropriate.

7) The fracture dimension used in this study was obtained from the previous simulation study. Since the compressibility and the failure data of the previous simulation study and calculated values from this study are different, it is recommended to run the models in the TARSIM system with the new compressibility and failure data to have accurate fracture dimension. Then, the new fracture radius should apply to the ENHANS model.

8) It is also recommended to do a grid block size sensitivity study and time step size sensitivity study to ensure the results are consistent.

9) The above conclusions and recommendations deal with laboratory and numerical studies, but have not been related to field results. The result of stress-strain behaviour should be reflected in various types of well behaviour in the field. A combined study consisting of field, laboratory and simulation work is the best approach to the problem. A framework for such combined study has been developed and is available from AOSTRA.

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1) Agar, J.: Behaviour of Oil Sands at Elevated Temperatures, Ph.D Thesis, University of Alberta, Edmonton, 1984.

2) Vaziri,H: "Finite Element Analysis of Oil Sands Subjected to Thermal Effects", Paper No. 86-37-74, 37th Annual Technical Meeting of CIM, 1986

3) Vaziri,H.: "Numerically-Derived Stress, Strain and Thermodynamic Properties of Athabasca Oil Sand", Paper CIM/SPE 90-26, Intnl. Meeting of CIM, Calgary, June 1990.

Table 1 **Parameters used in the Laboratory Study**

	B2P7T3	B1P8T3	C1P4T3	Correlated
k_ϕ	700	800	900	6420
n_ϕ	0.11	0.11	0.11	0.256
k_ψ	2000	1500	1000	2911.5
n_ψ	0.3	0.3	0.3	-0.1772
Φ	71	71	71	45
$\delta\Phi$	20	20	20	5
Φ_{max}	44.037	40.014	40.72	50.0

TABLE 2

DATA FOR THE SIMULATION OF THE HORIZONTAL FRACTURE

```
  FILE://nl/p/ito/pcej/stress/hfrac              September, 1990
  Data for the ENHANS program for horizontal fracture design
COM
COM  FINER MESH 9 X 5 BLOCKS
COM  GRID FOR HORIZONTAL FRACTURE
COM  INITIALIZATION DATA SECTION
COM ------------------------------------------------------------------------------
COM
COM LINK (LINK CODE TO MATCH GHANS DATA) IUNIT (UNITS)
     1    0
COM NPLAX NMAT INC1 INC2 IPRIM IUPD ICOR ISELF IPRTMH IGRAPH
     1    1    1   98    0    0    0    0    1    1
COM MXITER DICONV PATM  TIMIT
    5    0.       101.33    0.
COM ILW IHIGH IFLOW ITENS ICONS MODEBC IFRAC
  999    0    5    1    2    0    0
COM NODES FOR CUMULATING THE FLOW ACROSS THE FLOW BDY (IFLOW NODES)
    1    7   13   19   25
COM MATERIAL PROPERTIES (NMAT SETS OF DATA)  - LINEAR MATERIAL
COM ------------------------------------------------------------------------
COM  THIS IS THE SAME DATA AS USED IN CORE ANALYSIS EXCEPT FOR VOID SPACE
COM  WHICH IS AVERAGED.
COM ------------------------------------------------------------------------
COM MAT NTY
COM
    1    7
COM
COM   e     k    n     R    k      n      DUC  gamma  k       k
COM          e    e     f    b      b                   x       y
  .6476   636.7 .256  0.95 2961.5 -.1772  10.   20.  .3654    .3654
COM
COM  c       phi  /\phi lamda   nu  alpha   phi   lamda     B        B
COM                      u               st    cv       h     l        s
     0.      45.     5.    0.    21.5  0.   28.     0.      2.2E6    1E10
COM
COM  mu   T       H       R    U      S       S        alfa    phimx   alfa
COM        s               cs   l/g           f           l               s
    1.     0.      0.     0.    0.     1.      0.        0.     50.0     0.
COM
COM ISIGE ISIGB IDILAT ILSHED
COM       1     1    1      2
    1     1    0      0
COM EXPRF1  EXPRF2  PHICVP  (3F10.0)
 1.0        2.0        0.87
COM ------------------------------------------------------------------------
COM  BOUNDARY BONDITION AND RECURRENT DATA
COM ------------------------------------------------------------------------
COM L(1) ...L(IPRIM) - ONLY IF IPRIM >0
COM
COM DEFINITION OF IN-SITU (MACRO-) MESH NODES
COM INSIT NN1 NELI NOUT
    1    4    2    1
COM INITIAL EFFECTIVE STRESS+PRESSURE CONDITIONS ON IN-SITU MESH NODES
COM NI    XI         YI       SIGX    SIGY   SIGZ TAUXY     U
    1     0.057        0.    6220.   6200.  6220   0.    1921.
    2     500.0        0.    6220.   6200.  6220   0.    1921.
    3     500.0     14.5     6220.   6200.  6220   0.    1921.
    4     0.057     14.5     6220.   6200.  6220   0.    1921.
COM DEFINE IN-SITU ELEMENTS IN TERMS OF IN-SITU NODES
COM LI  NI1  NI2  NI3
    1    1    2    3
```

```
    2    1    3    4
COM RECURRENT DATA SECTION
COM ------------------------------------------------------------------------------
COM
COM INC ICHEL NLOD IFIX  IOUT   DTIME     DGRAV    NSINC NTEMP
    1     0     0    34  0011   0.0025          0.     1      0
COM ADD OR DELETE ELEMENTS (ONLY IF ICHEL > 0)
COM
COM INCREMENTS OF LOAD FROM PREVIOUS COND. (ONLY IF NLOD.NE.0)
COM
COM INCREMENT DISPLACEMENTS DX,DY OR PRESSURE DU B.C. (ONLY IF IFIX>0)
COM
COM N ICODE    DX    DY    DU
COM  PRESSURE B.C. AT FRACTURE
COM  NO MOVEMENT IN X- AND Y- DIRECTION
    1  111     0     0   6200.
COM  NO MOVEMENT IN Y-DIRECTION
    7  011     0     0   6200.
   13  011     0     0   6200.
   19  011     0     0   6200.
   25  011     0     0   6200.
COM B.C. EVERYWHERE ELSE
COM  Y=0 - CENTERLINE BEYOND THE FRACTURE
COM  NO MEVEMENT IN Y-DIRECTION
COM  NO PRESSURE PRESCRIPTION AT THE BOUNDARY
   820   010   0.    0.    0.
    31   010   0.    0.    0.
   836   010   0.    0.    0.
    37   010   0.    0.    0.
   852   010   0.    0.    0.
    43   010   0.    0.    0.
   868   010   0.    0.    0.
    49   010   0.    0.    0.
   884   010   0.    0.    0.
    55   010   0.    0.    0.
COM  RIGHT SIDE - 500 M FROM THE WELL
COM  NO MOVEMENT ON X- AND Y-DIRECTION
COM  NO CHANGE IN PRESSURE
   885   112   0.    0.    0.
    56   112   0.    0.    0.
   888   112   0.    0.    0.
    57   112   0.    0.    0.
   891   112   0.    0.    0.
    58   112   0.    0.    0.
   894   112   0.    0.    0.
    59   112   0.    0.    0.
   897   112   0     0     0
    60   112   0     0     0
COM  TOP OF THE FORMATION
COM  CAN MOVE X- AND Y-DIRECTION
COM  NO CONSTRAINT IN PRESSURE
COM
COM  X=0, WELLBORE
COM  NO MOVEMENT IN X-DERECTION
COM  FREE MOVEMENT IN Y-DIRECTION
COM  NO CONSTRAINT IN PRESSURE
   771   100   0     0     0
     5   100   0     0     0
   767   100   0     0     0
     4   100   0     0     0
   763   100   0     0     0
     3   100   0     0     0
   759   100   0     0     0
     2   100   0     0     0
   755   100   0     0     0
COM INC ICHEL NLOD IFIX  IOUT   DTIME     DGRAV    NSINC NTEMP
```

```
    2    0    0    5     0000   0.0025          0.     1      0
COM  USE SAME INCREMENT EACH T.S.
COM     N ICODE     DX     DY     DU
    1    111   0.     0.    0.0
    7    011   0.     0.    0.0
   13    011   0.     0.    0.0
   19    011   0      0     0.0
   25    011   0      0     0.0
COM INC ICHEL NLOD IFIX   IOUT    DTIME      DGRAV     NSINC NTEMP
    3    0    0    0     0000   0.0025          0.     1      0
    4    0    0    0     0010   0.0025          0.     1      0
    5    0    0    0     0000   0.01            0.     1      0
    6    0    0    0     0000   0.01            0.     1      0
    7    0    0    0     0000   0.01            0.     1      0
    8    0    0    0     0000   0.01            0.     1      0
    9    0    0    0     0000   0.025           0.     1      0
   10    0    0    0     0010   0.025           0.     1      0
   11    0    0    0     0000   0.05            0.     1      0
   12    0    0    0     0000   0.05            0.     1      0
   13    0    0    0     0000   0.1             0.     1      0
   14    0    0    0     0000   0.1             0.     1      0
   15    0    0    0     0000   0.15            0.     1      0
   16    0    0    0     0000   0.15            0.     1      0
   17    0    0    0     0000   0.15            0.     1      0
   18    0    0    0     0011   0.15            0.     1      0
COM  END OF 1 DAY

                        .
                        .
              MORE TIME STEP DATA FOLLOWS
                        .

END
EOF
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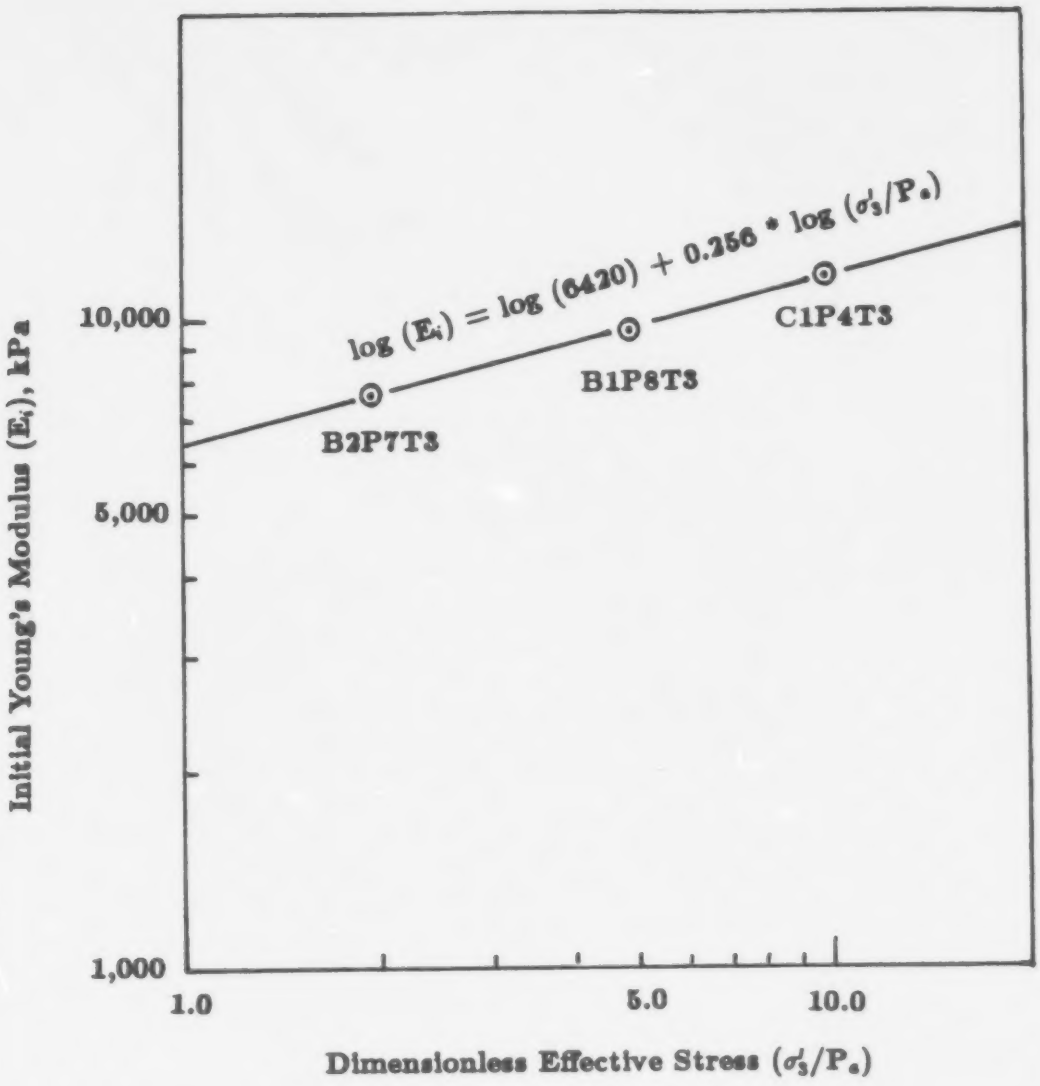


Fig. 1 Variation of Initial Young's Modulus with Effective Stress

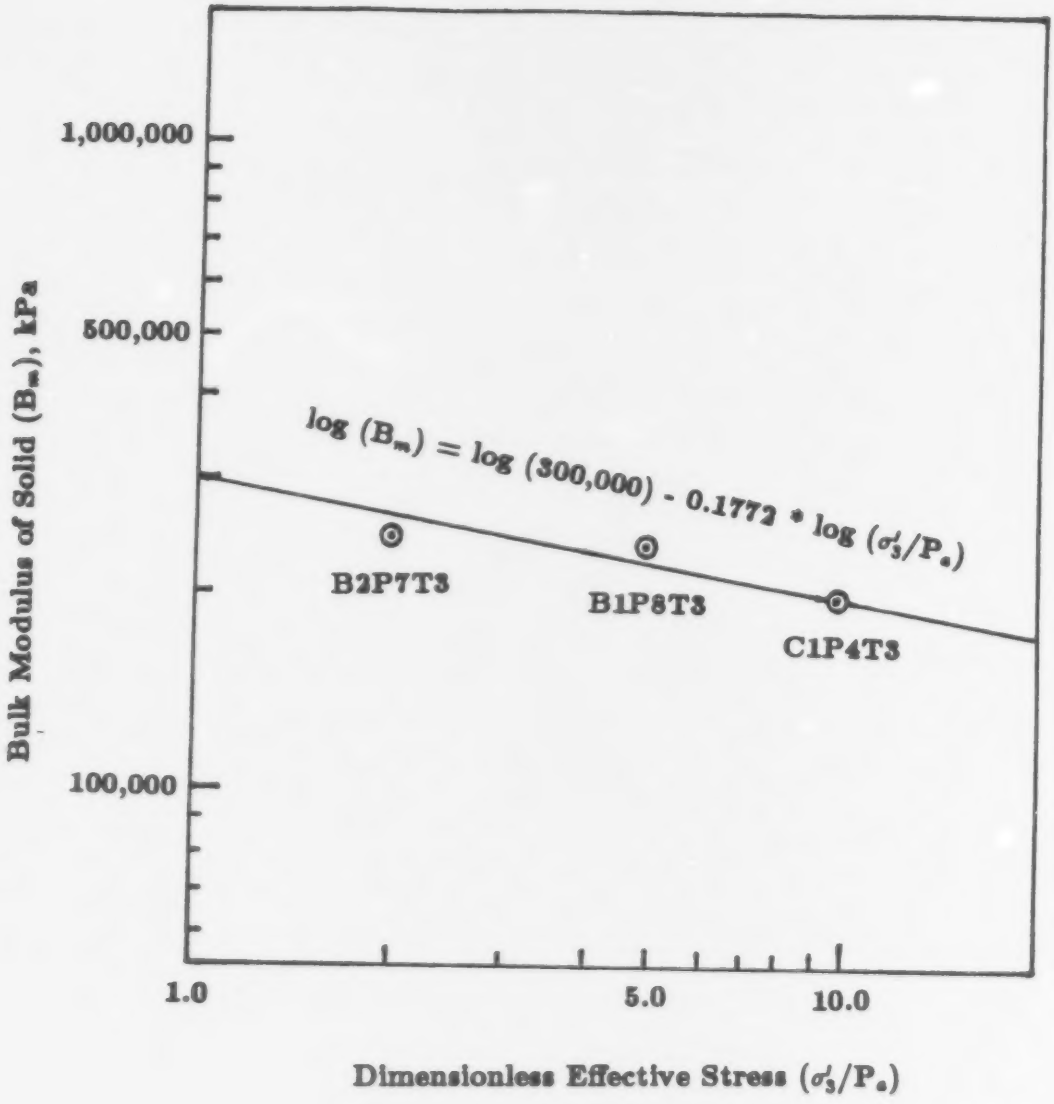


Fig. 2 Variation of Solid Bulk Modulus with Effective Stress

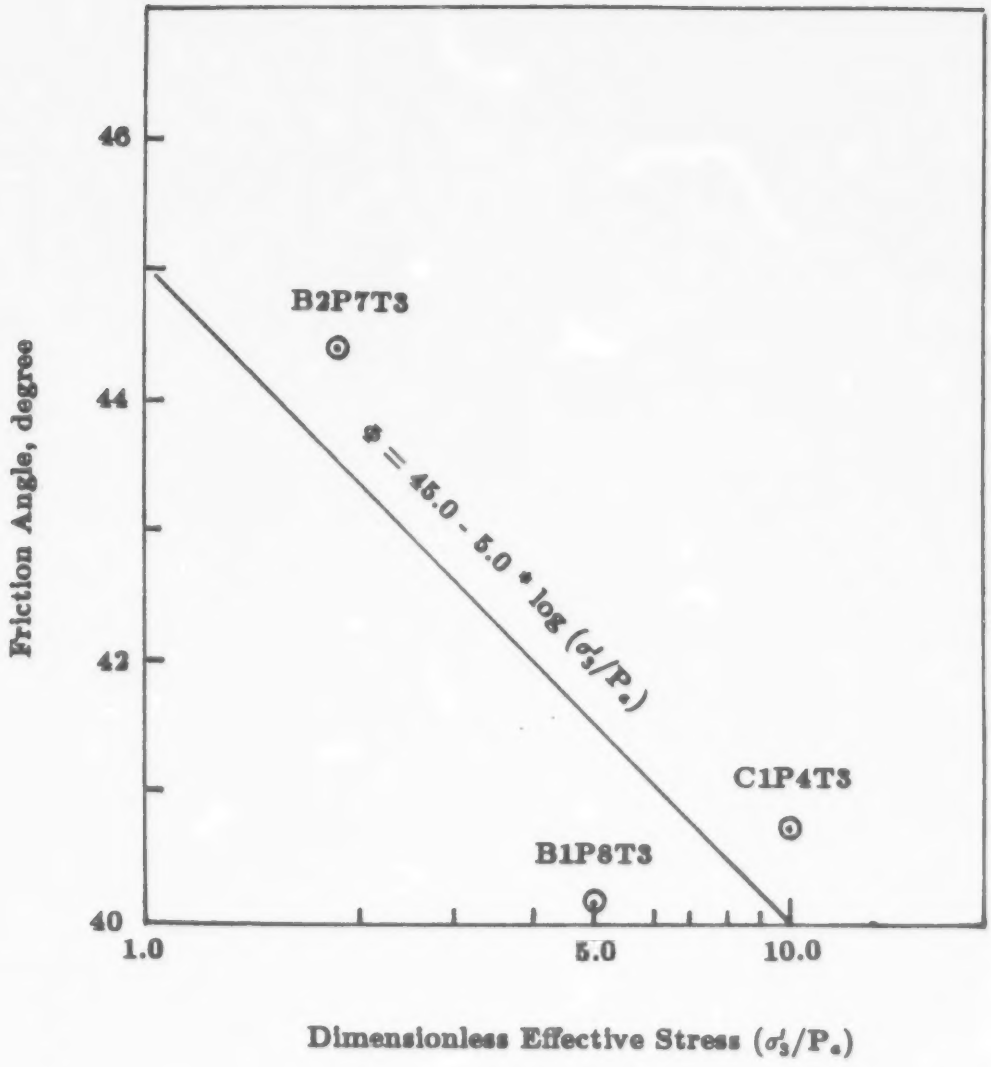
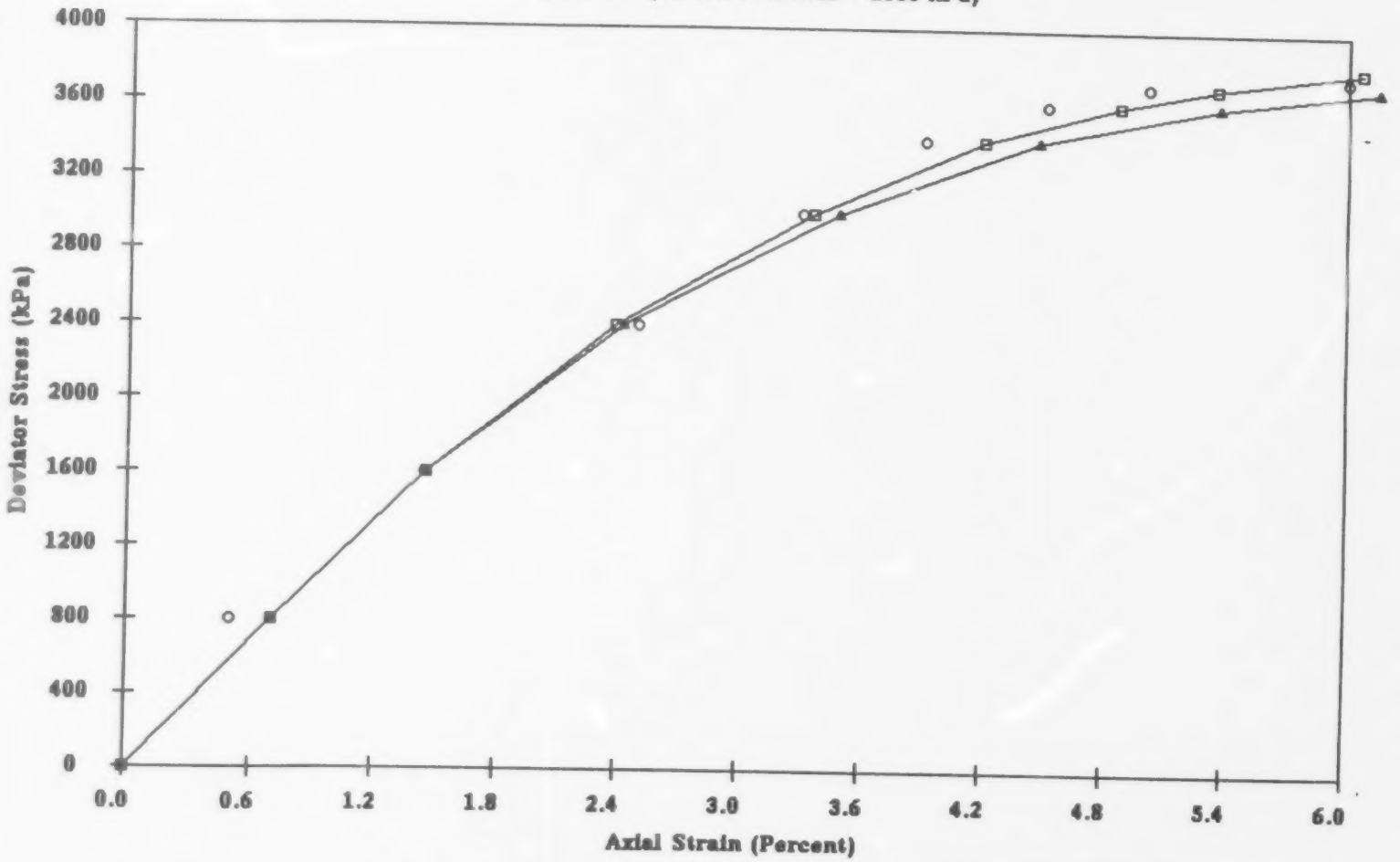


Fig. 3 Variation of Friction Angle with Effective Stress



○ Laboratory Mesurement
□ Calcurated (History Match)
▵ Calcurated (Correlated Prop.)

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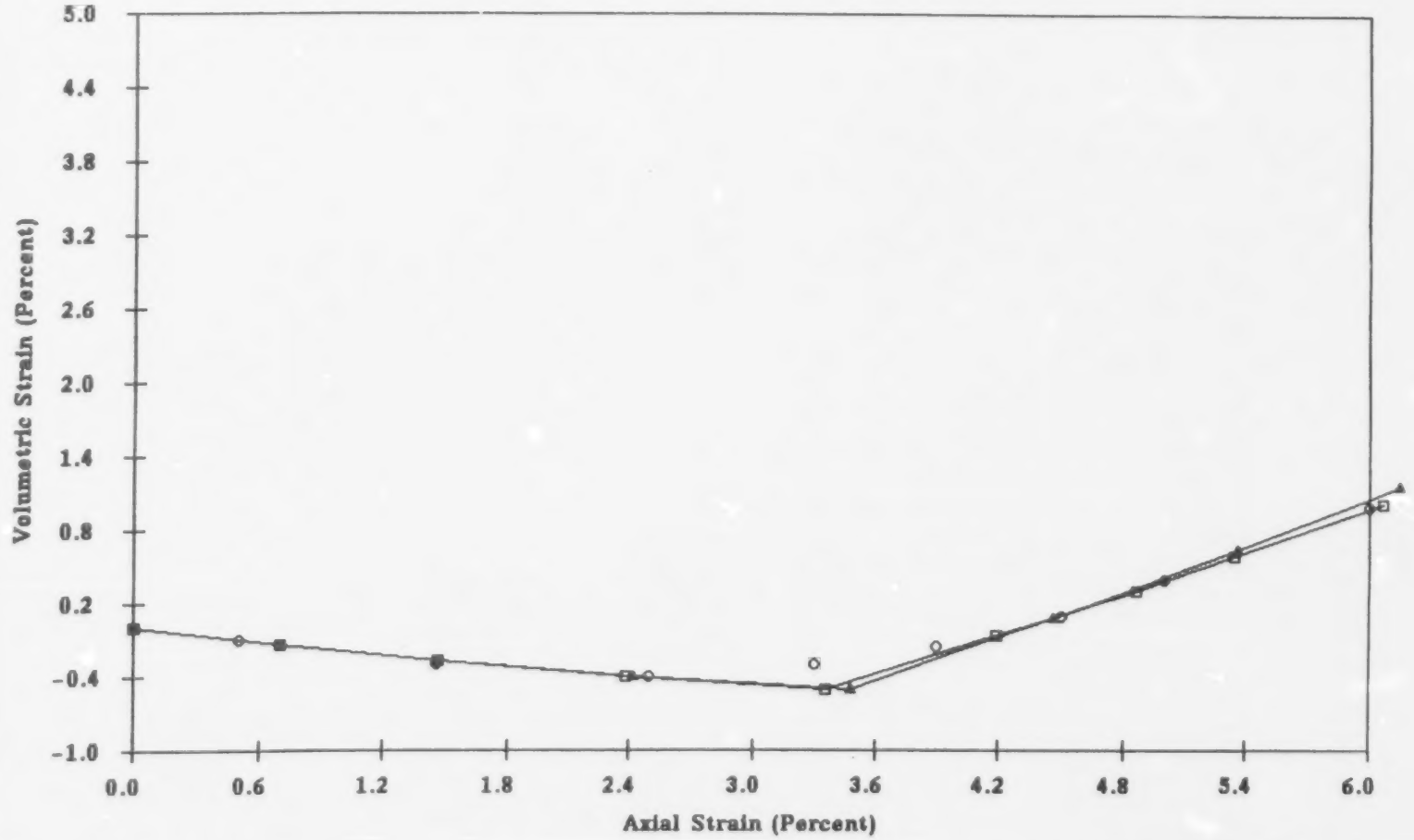
of Tar Sands

Date: August 1998 | Figure: 4



○ Laboratory Mesurement
□ Calcurated (History Match)
▵ Calcurated (Correlated Prop.)

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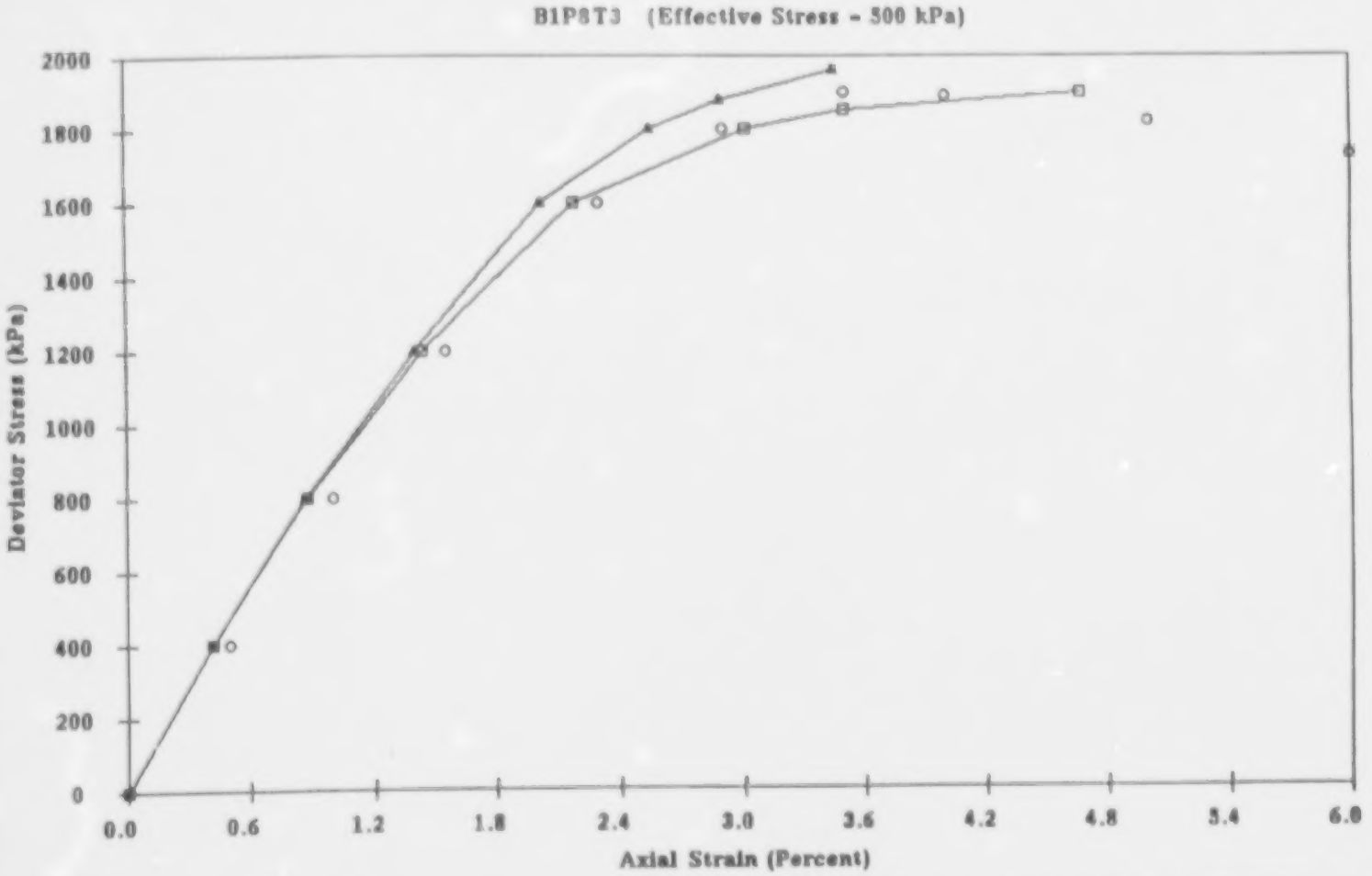
of Tar Sands

Date: August 1990 | Figure: 5



○ Laboratory Mesurement
□ Calcurated (History Match)
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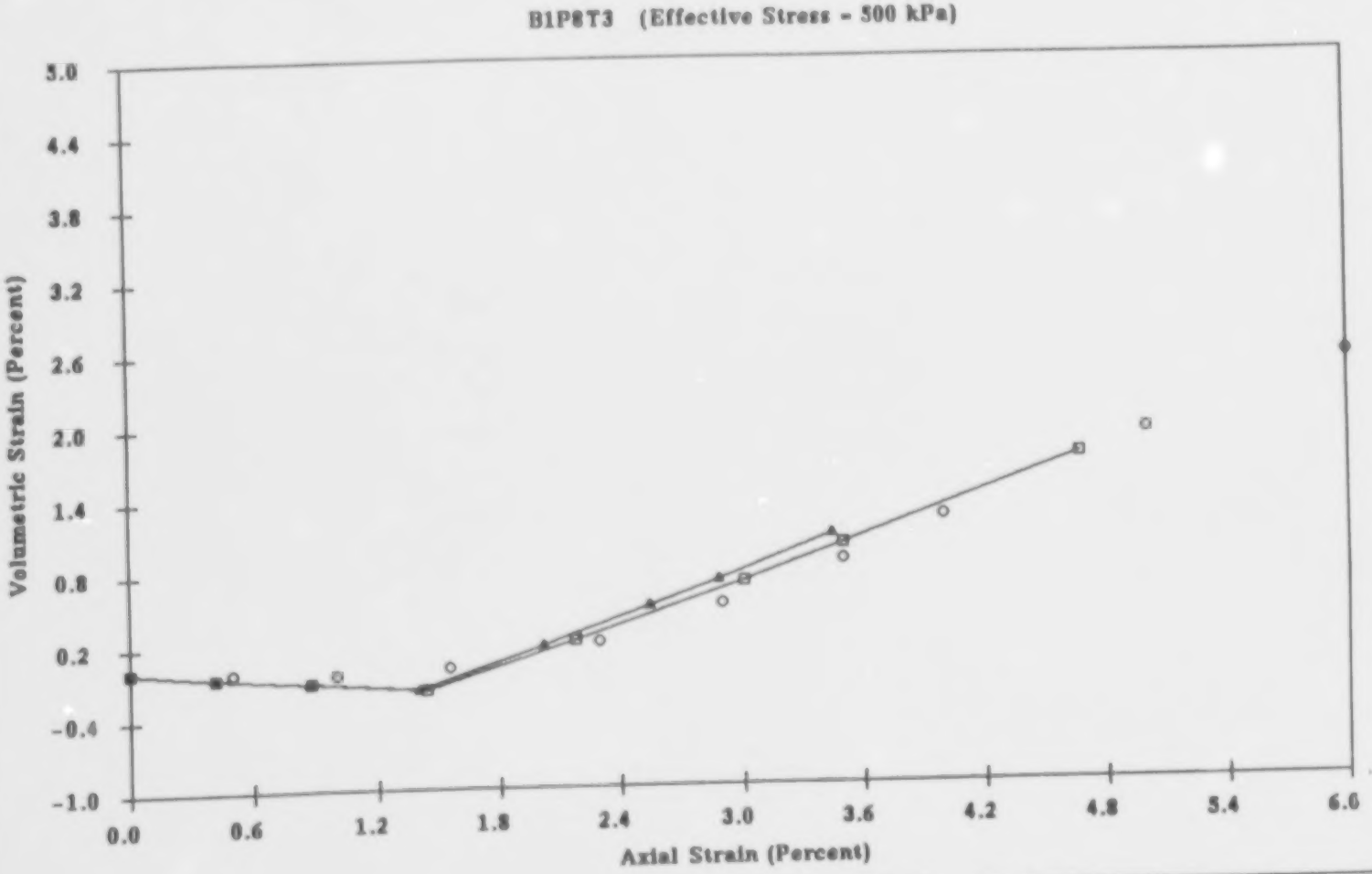
of Tar Sands

Date: August 1990 | Figure: 8



○ Laboratory Mesurement
□ Calcurated (History Match)
▵ Calcurated (Correlated Prop.)

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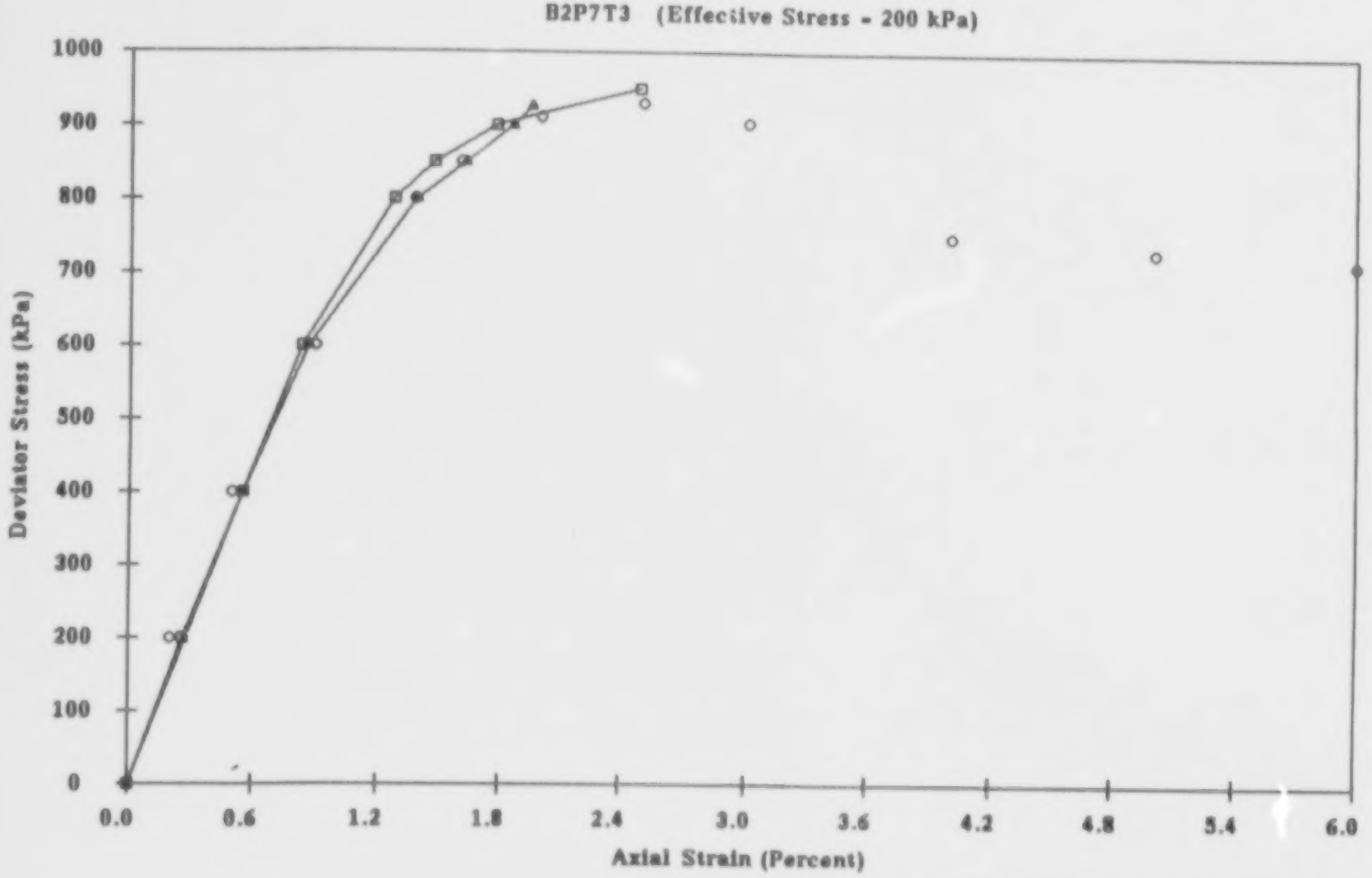
of Tar Sands

Date: August 1998 | Figure: 7



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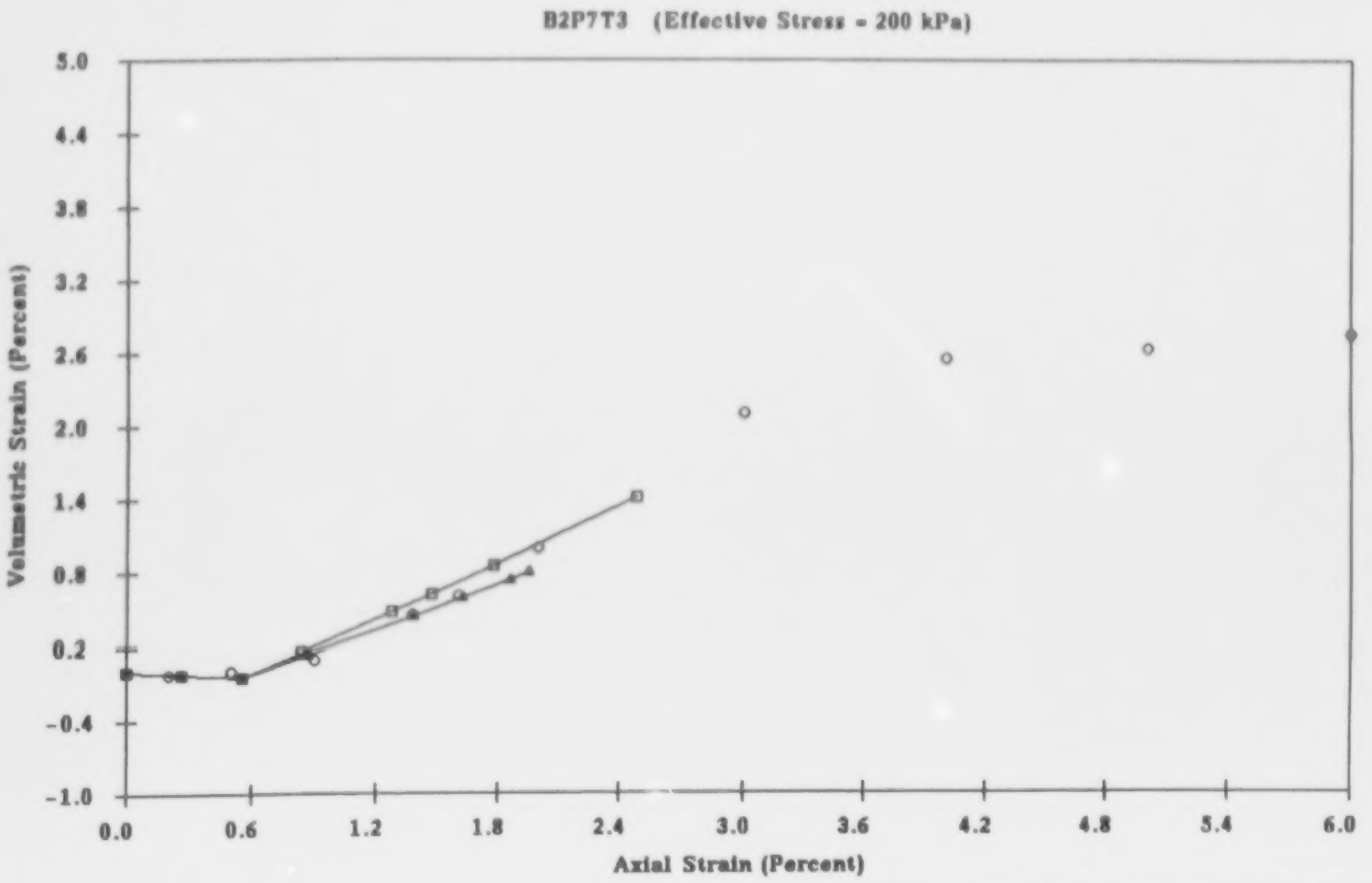
of Tar Sands

Date: August 1998 | Figure: 8



○ Laboratory Mesurement
□ Calcurated (History Match)
▵ Calcurated (Correlated Prop.)

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of Tar Sands

Date: August 1998 | Figure: 9

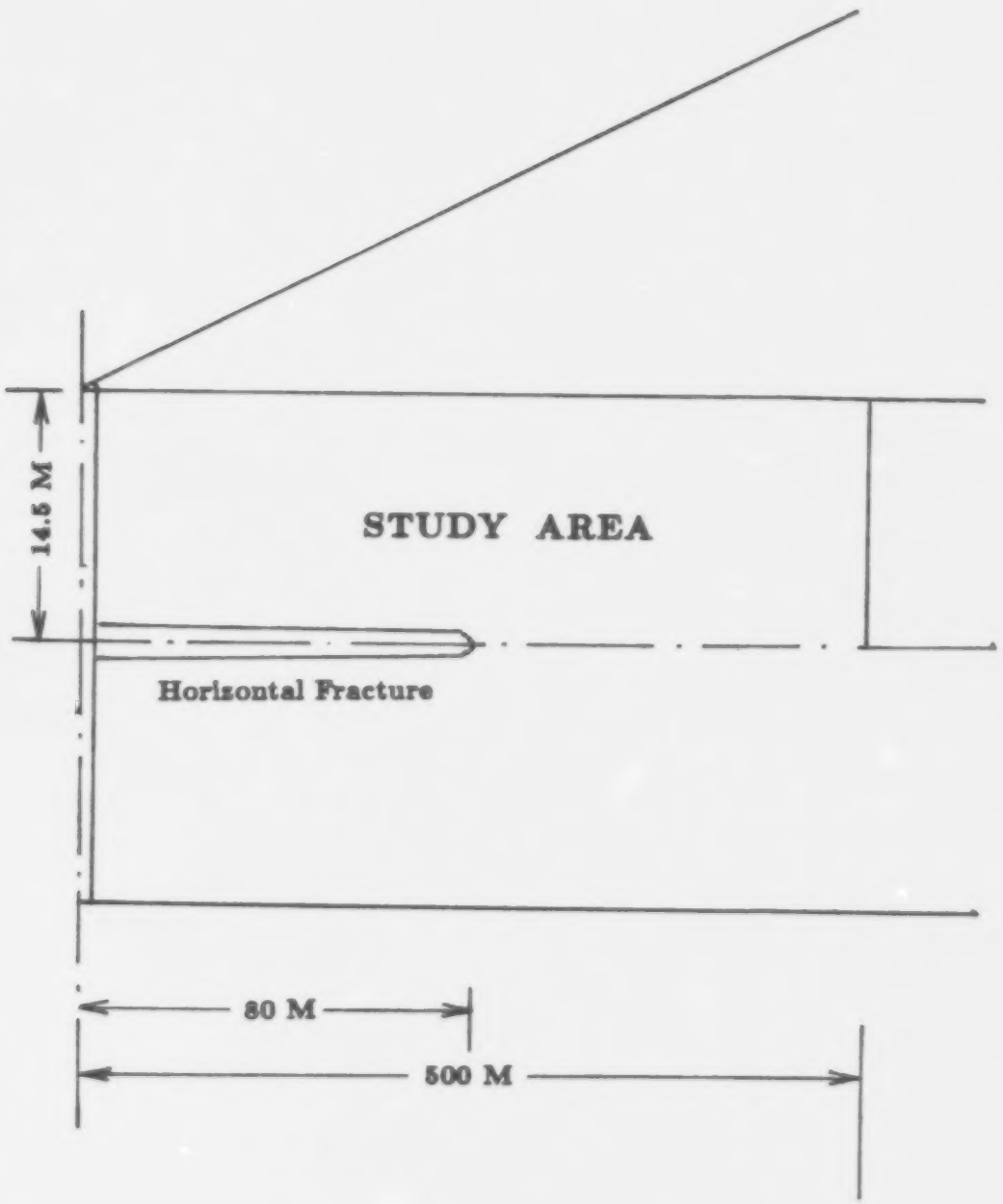


Fig. 10 Schematic view of the study area

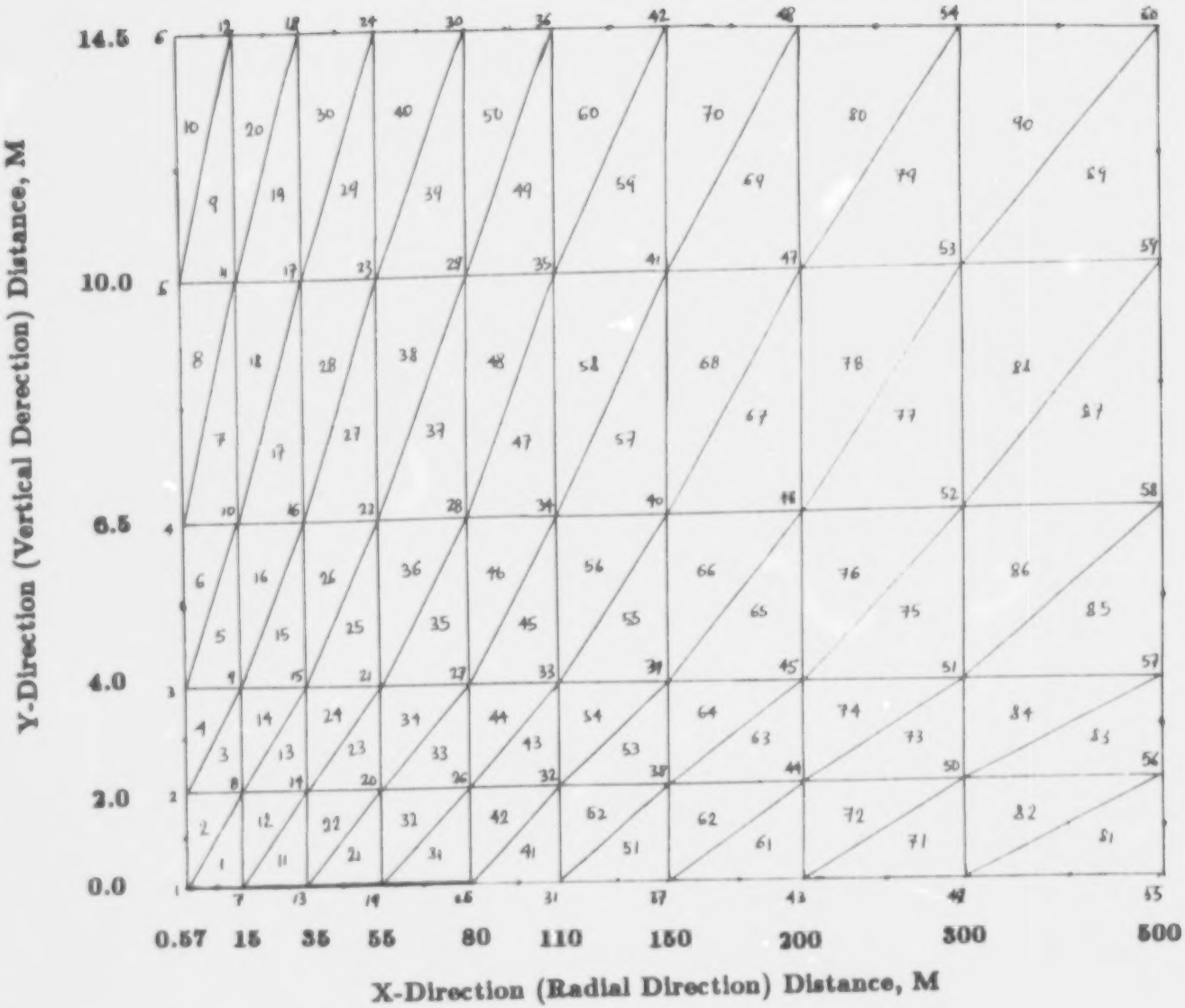
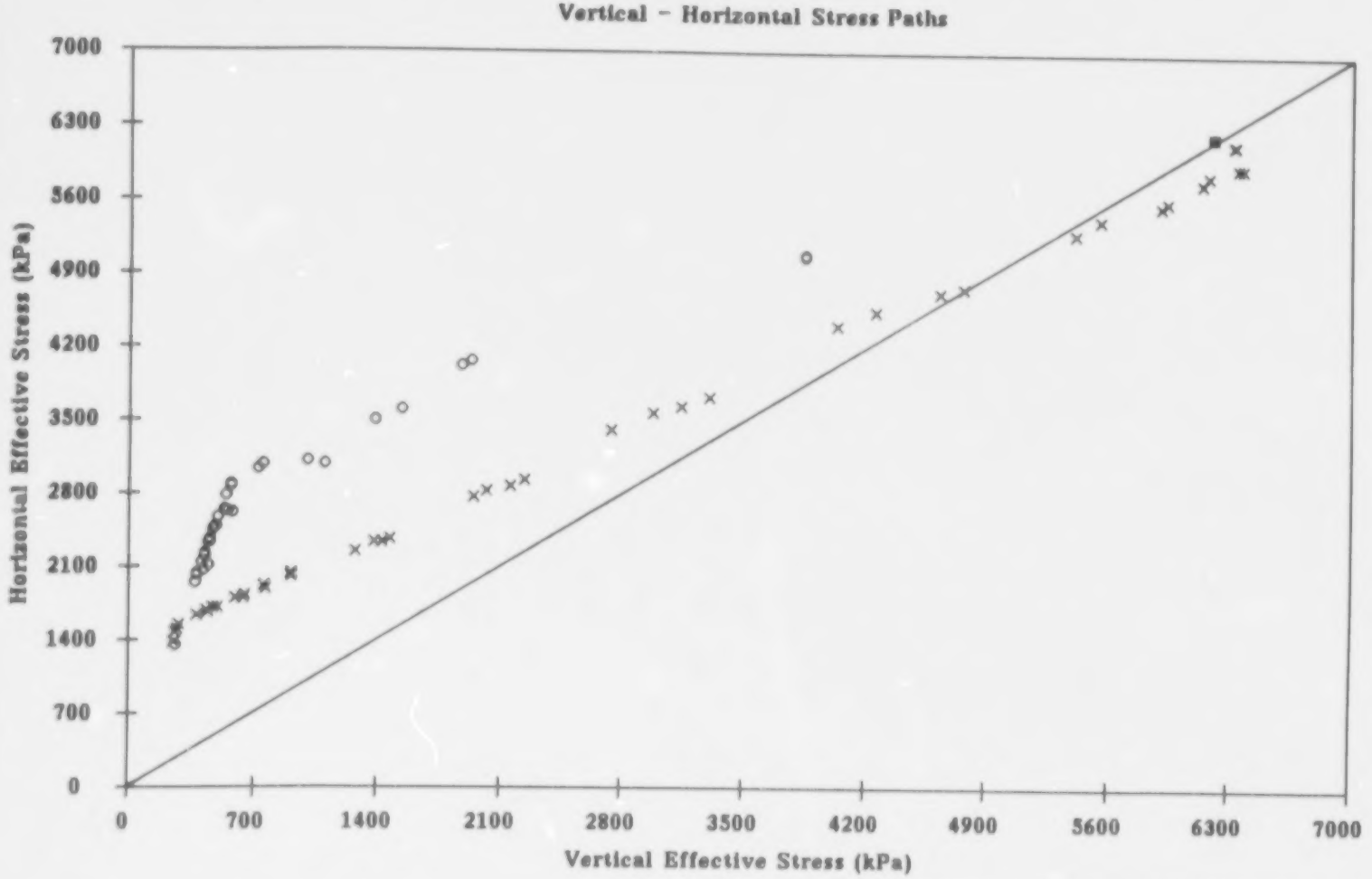


Fig. 11 Finite element grid used in the reservoir study



○ Block 11,12,31,32
× Block 17,18,37,38

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in Tar Sands

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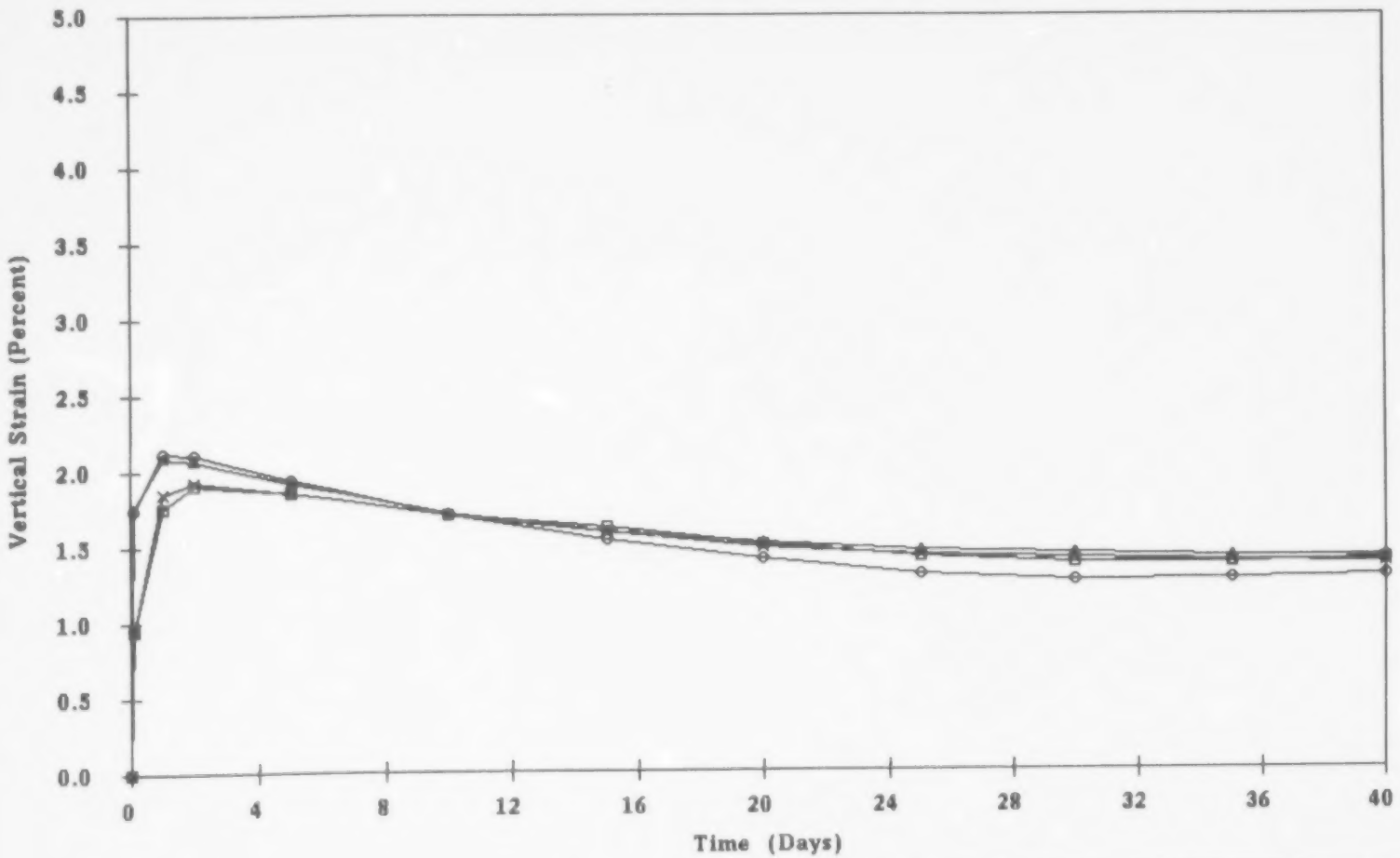

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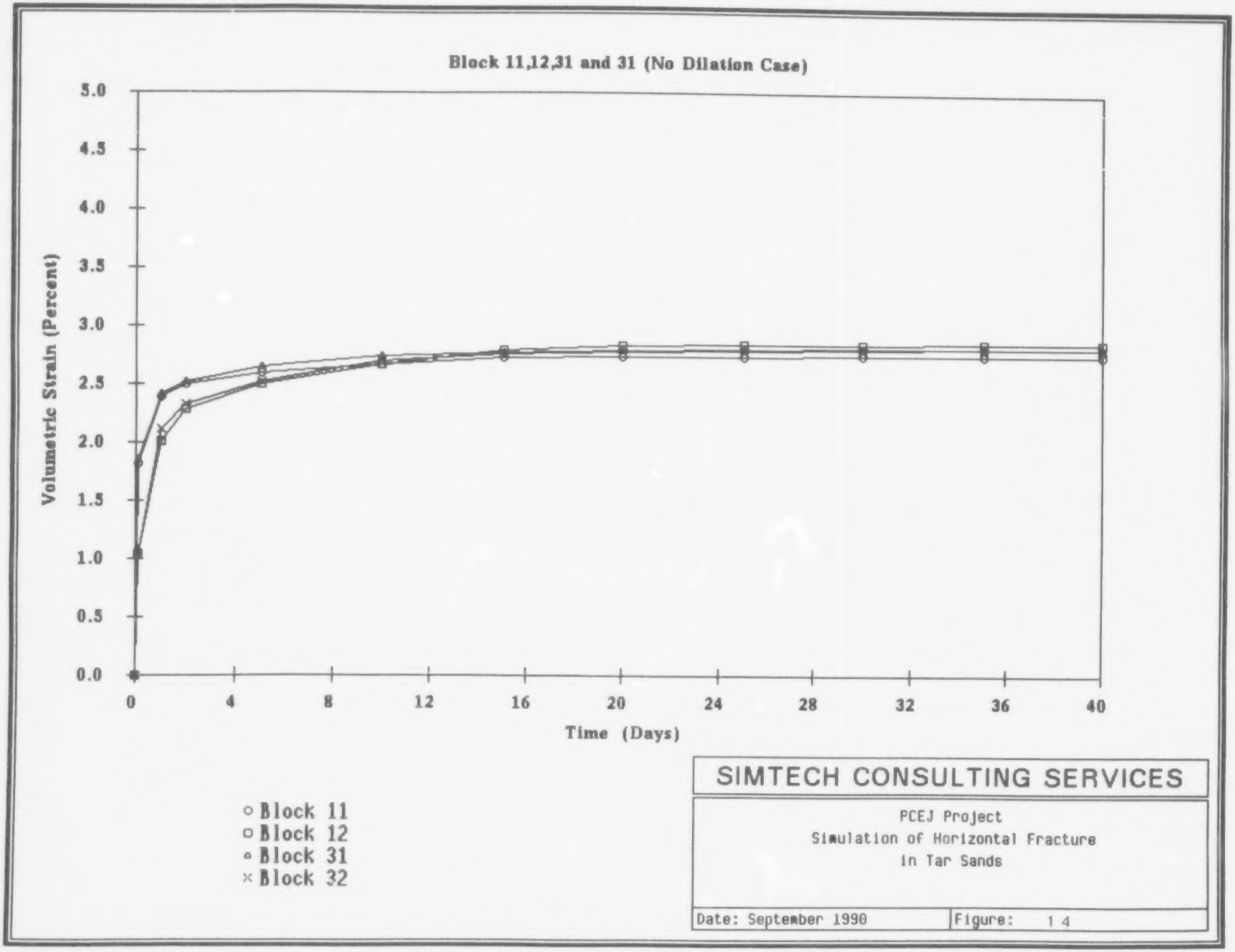
Simulation of Horizontal Fracture
in Tar Sands

Date: September 1990 | Figure: 13


Block 11,12,31 and 31 (No Dilation Case)
Volumetric Strain (Percent)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
4
8
12
16
20
24
28
32
36
40
Time (Days)
Block 11
Block 12
Block 31
Block 32
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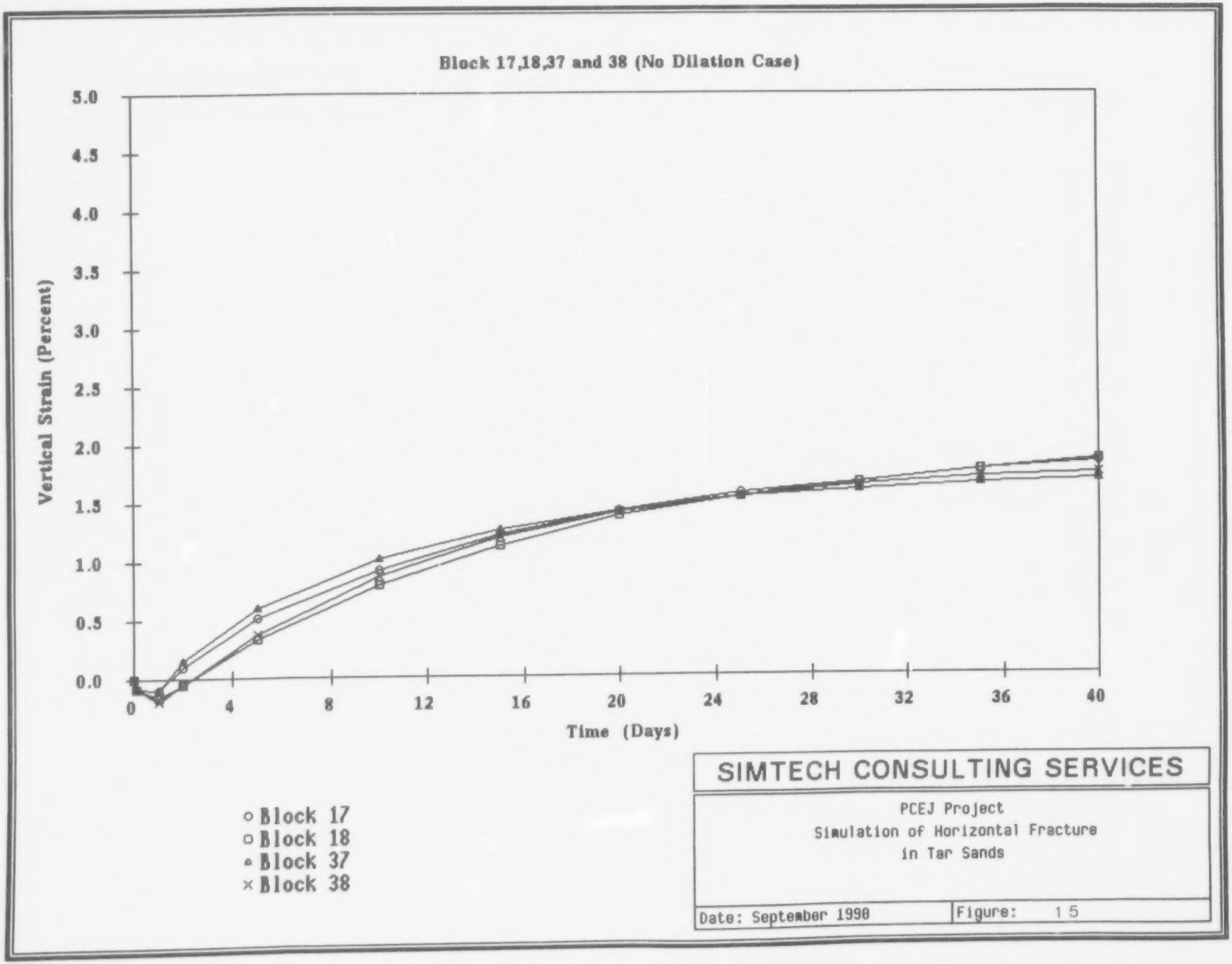
Simulation of Horizontal Fracture
in Tar Sands
Date: September 1990
Figure: 14


Block 17,18,37 and 38 (No Dilation Case)
Vertical Strain (Percent)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
4
8
12
16
20
24
28
32
36
40
Time (Days)
Block 17
Block 18
Block 37
Block 38
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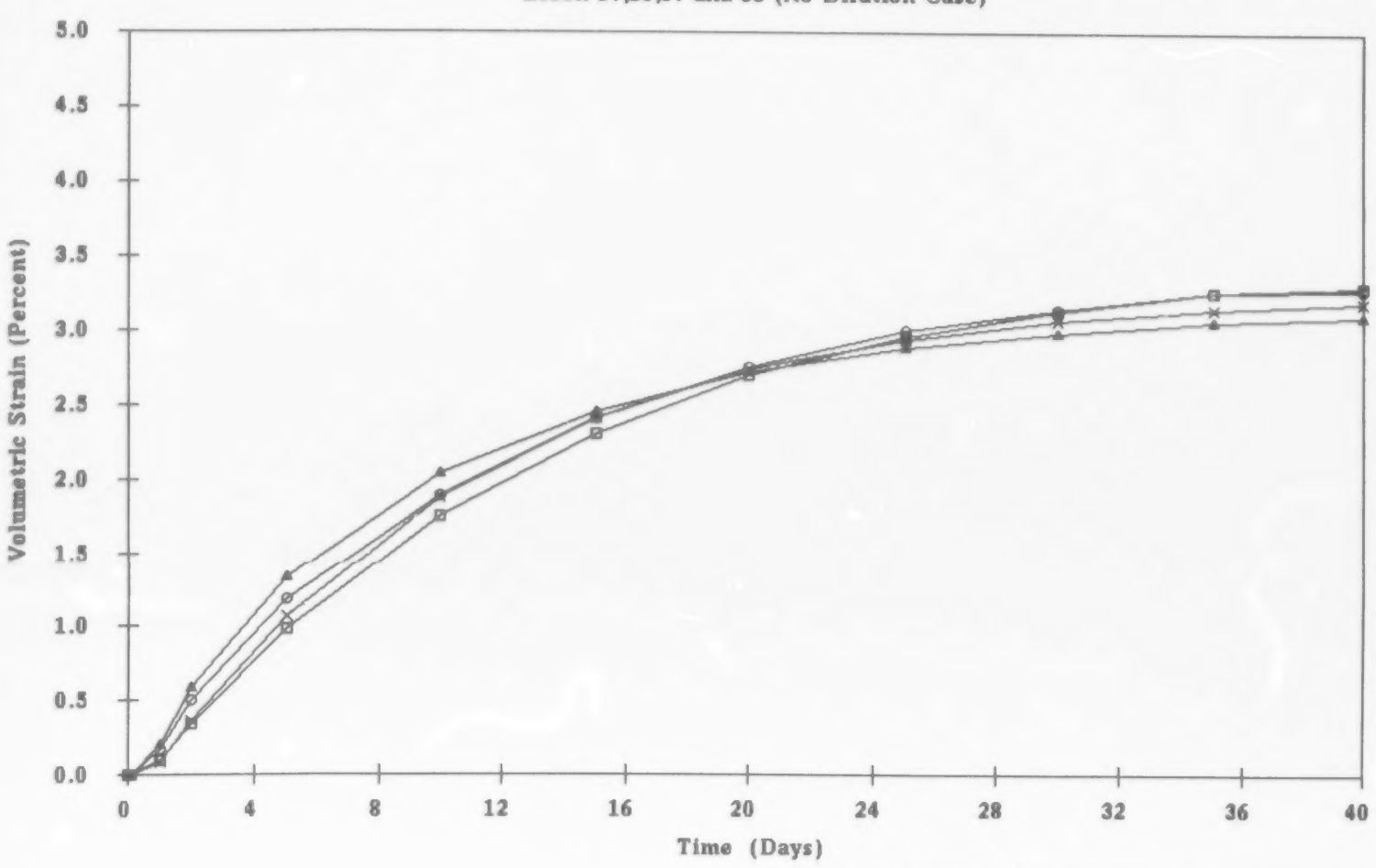
in Tar Sands
Date: September 1998
Figure: 15



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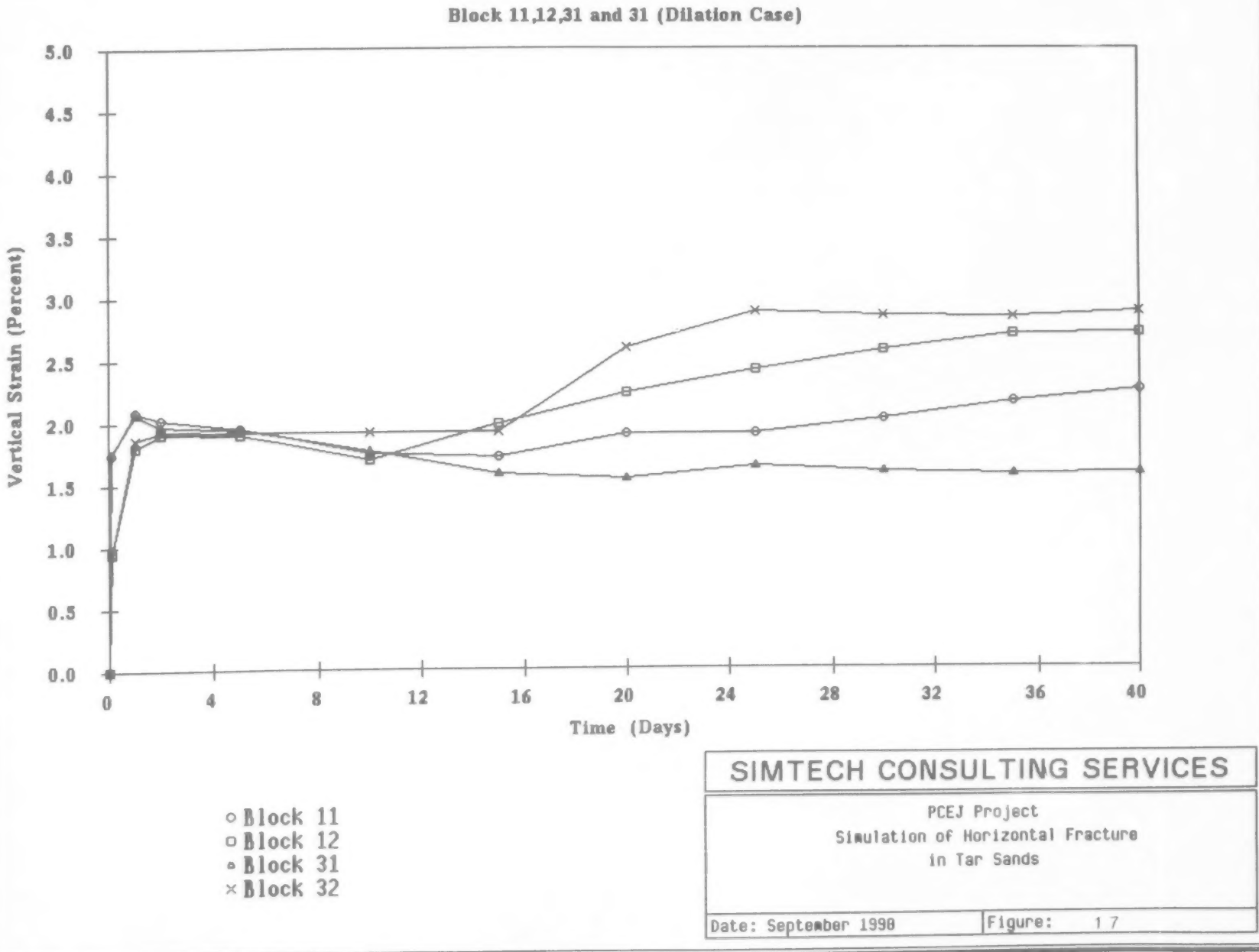
in Tar Sands

Date: September 1998 | Figure: 16


Block 11,12,31 and 31 (Dilation Case)
Vertical Strain (Percent)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
4
8
12
16
20
24
28
32
36
40
Time (Days)
Block 11
Block 12
Block 31
Block 32
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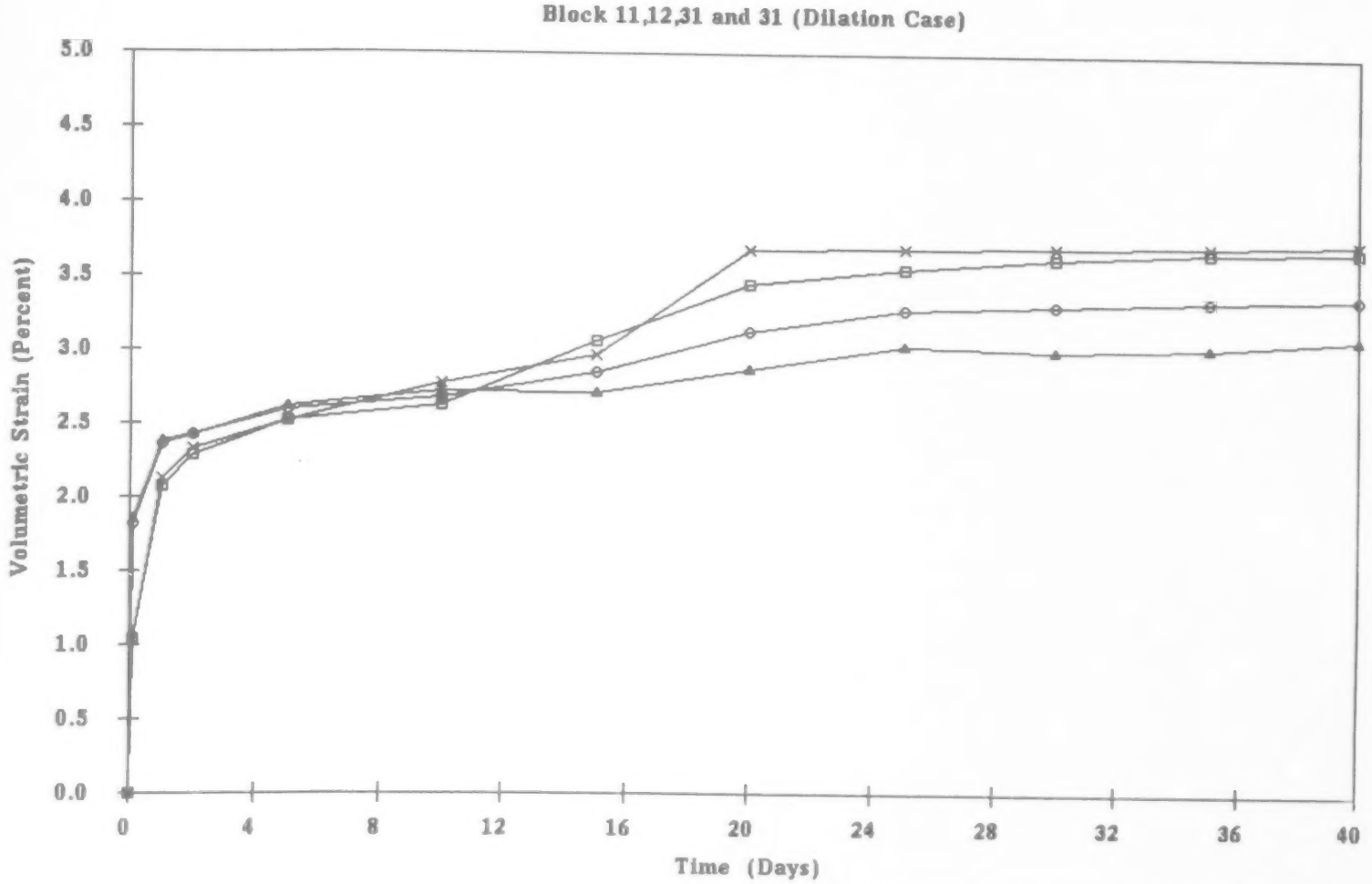
Simulation of Horizontal Fracture
in Tar Sands
Date: September 1998
Figure: 17



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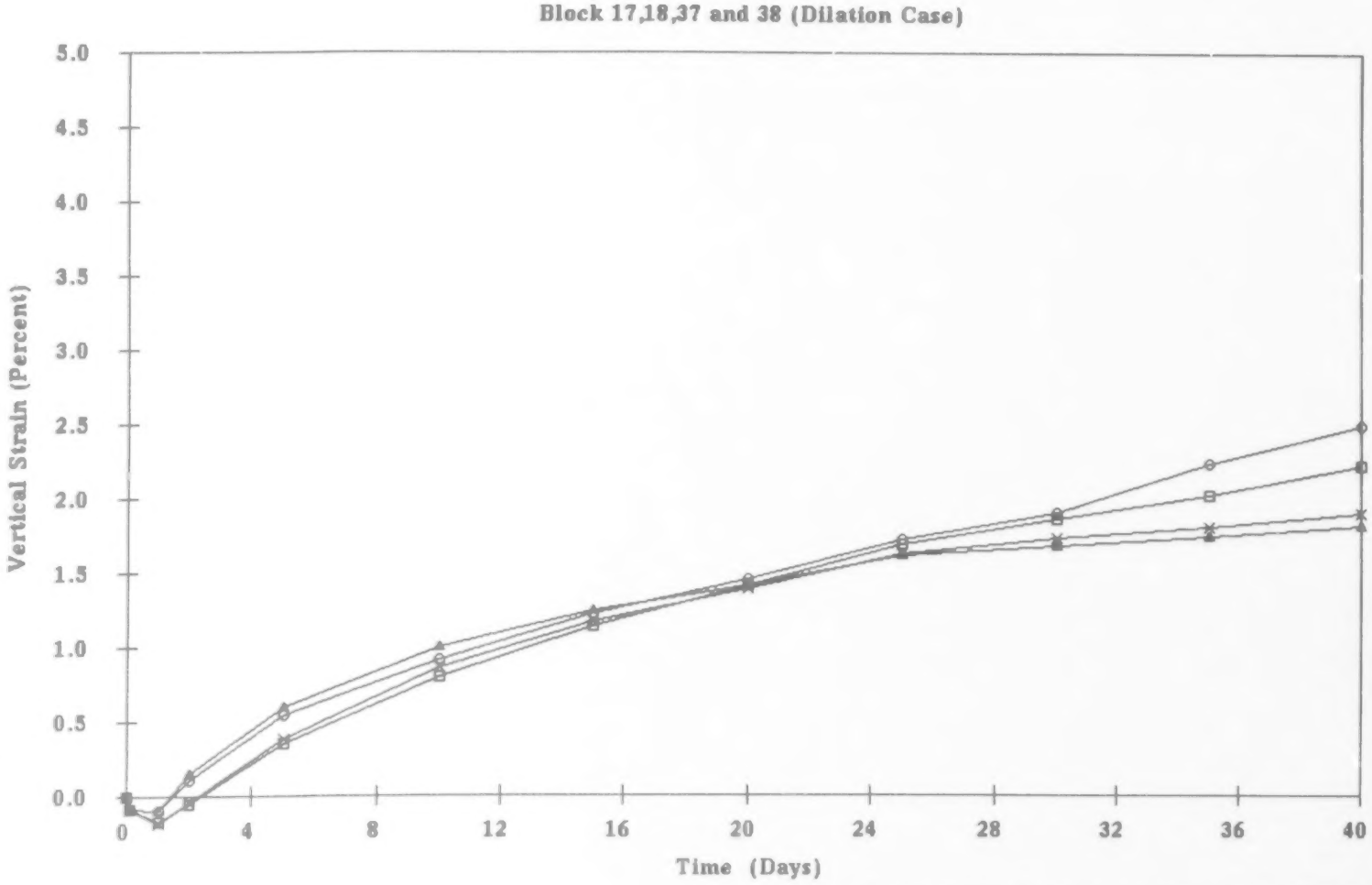
Date: September 1998 | Figure: 18



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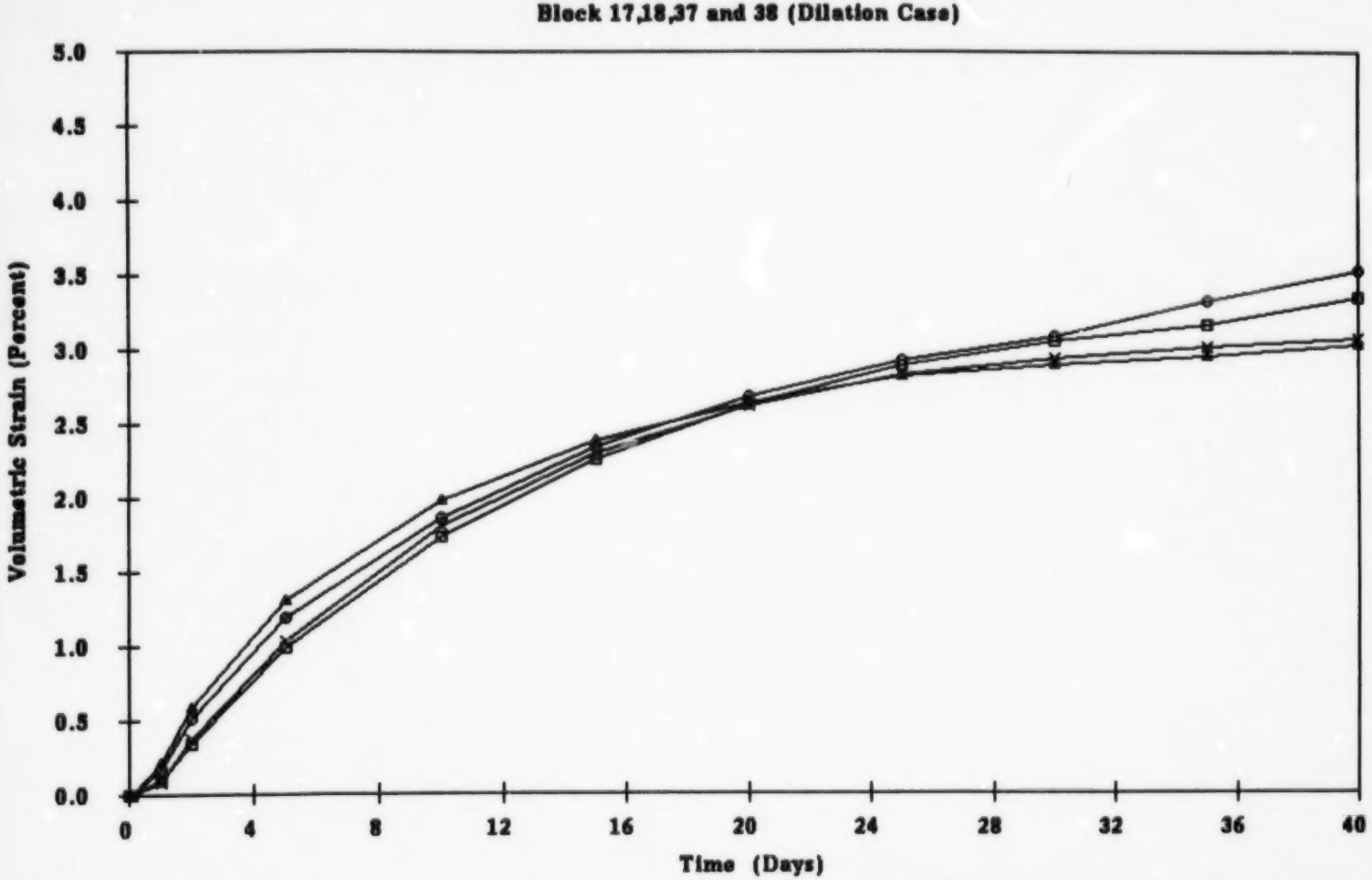
Simulation of Horizontal Fracture
in Tar Sands

Date: September 1990 | Figure: 19



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in Tar Sands

Date: September 1998 | Figure: 20

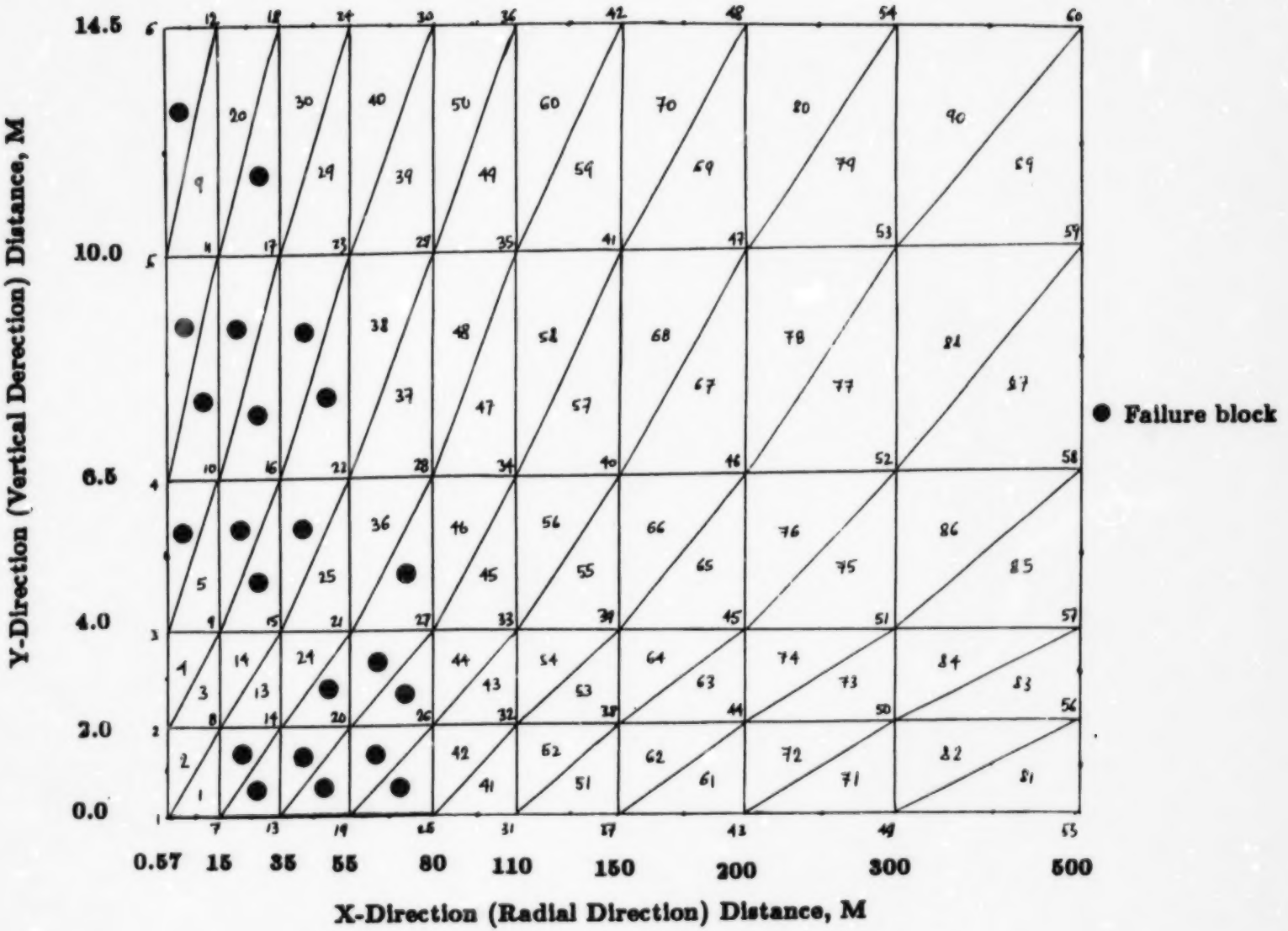
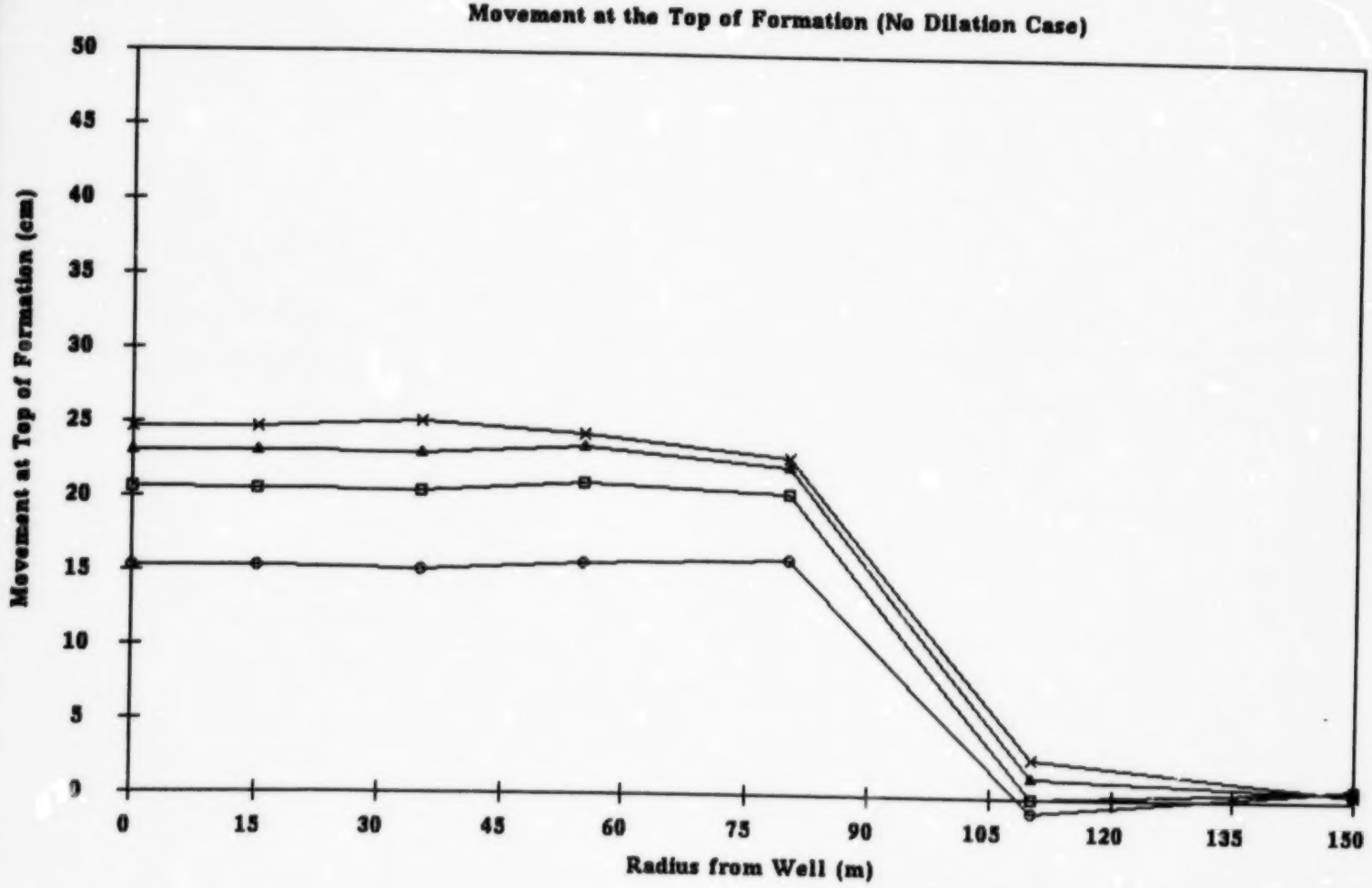


Fig. 21 Extension of failure block at the end of 40 days of injection



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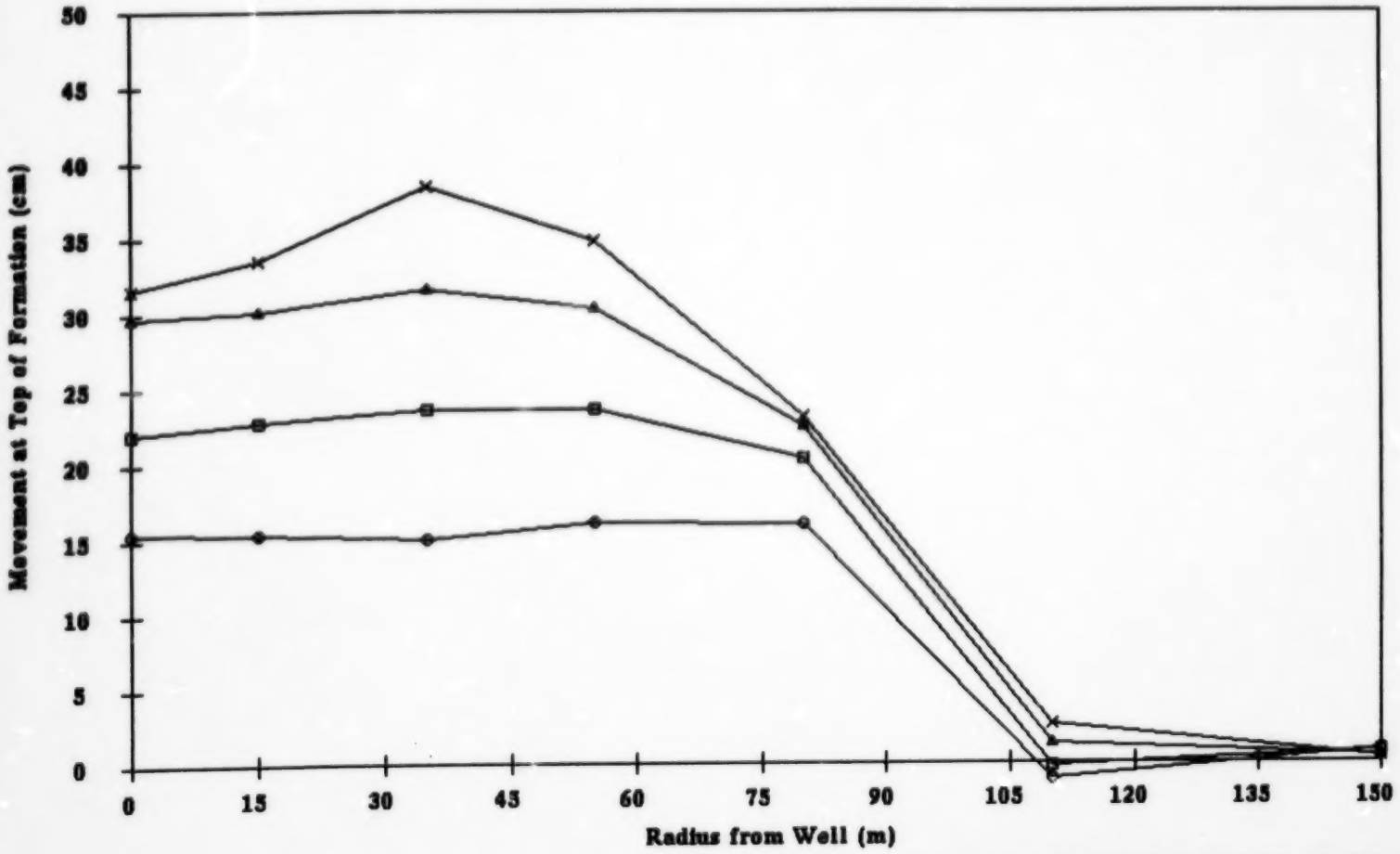
in Tar Sands

Date: September 1998 | Figure: 22

Movement at the Top of Formation (Dilation Case)



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in Tar Sands

Date: September 1990 | Figure: 23

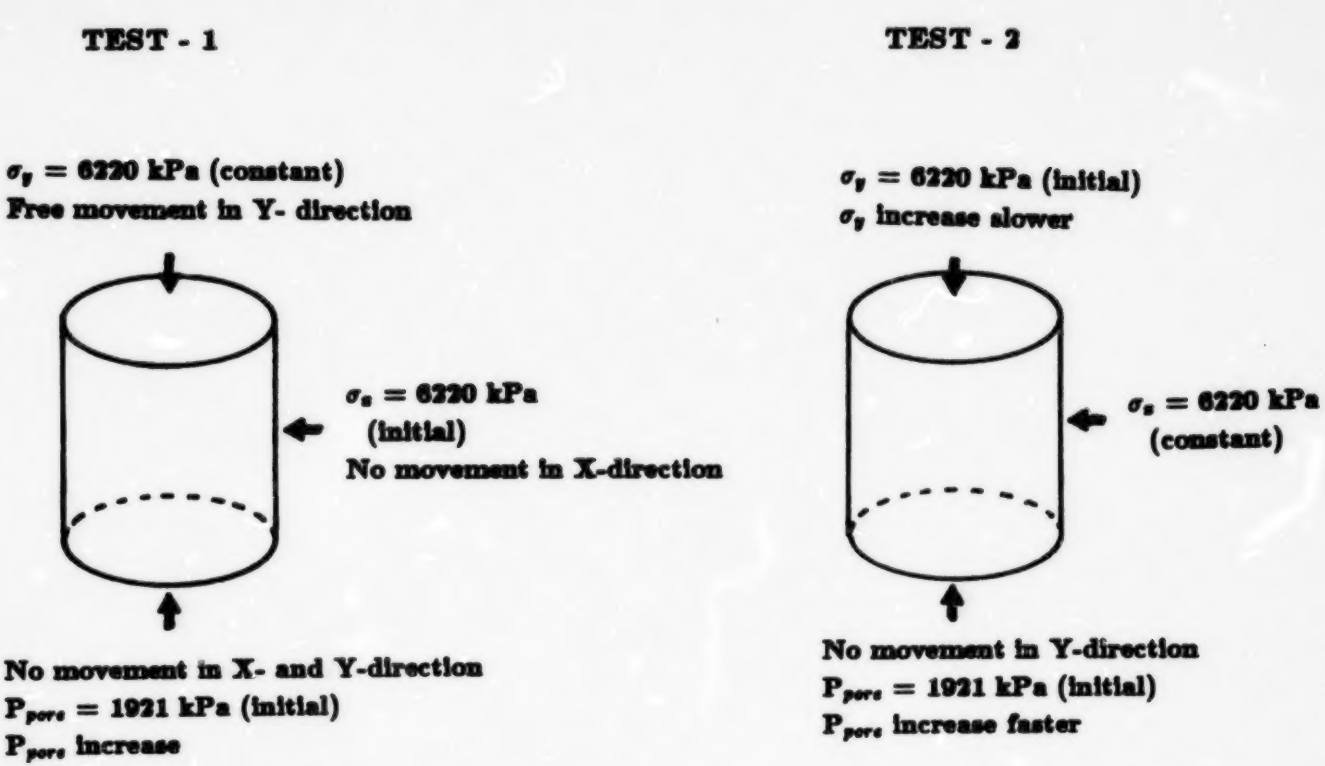
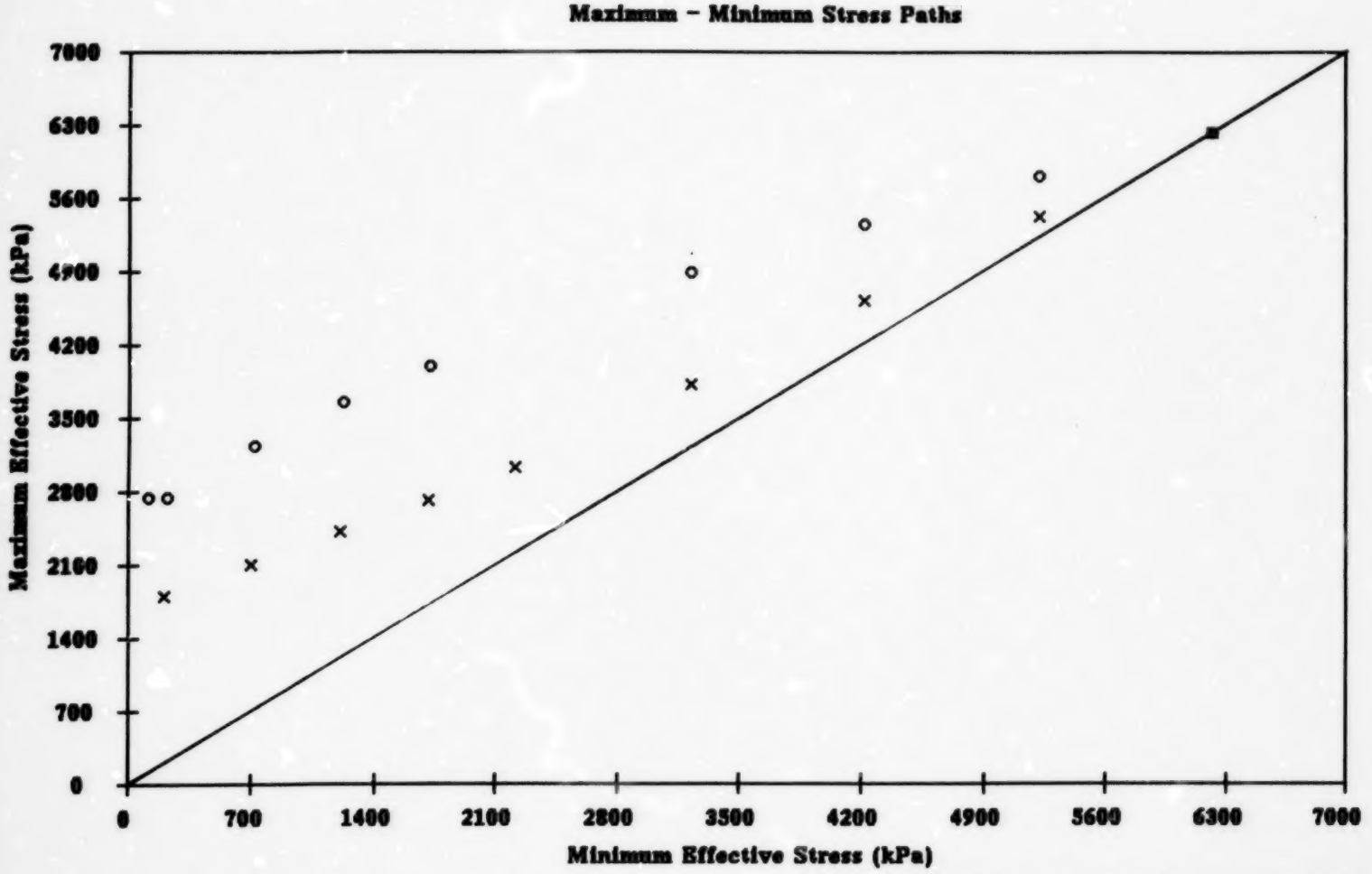


Fig. 24 Schematic of hypothetical laboratory core tests



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Test of Tar Sand

Date: September 1998 | Figure: 25